IDA

INSTITUTE FOR DEFENSE ANALYSES

Climate Change: Issues in the Science and Its Use

Christine Youngblut

July 2009
Approved for public release;
unlimited distribution.
IDA Document D-3904
Log: H 09-000863

The Institute for Defense Analyses is a non-profit corporation that operates three federally funded research and development centers to provide objective analyses of national security issues, particularly those requiring scientific and technical expertise, and conduct related research on other national challenges.

About This Publication

This work was conducted under IDA's independent research program (C2222). The views, opinions, and findings should not be construed as representing the official position of the Department of Defense.

Copyright Notice

INSTITUTE FOR DEFENSE ANALYSES

IDA Document D-3904

Climate Change: Issues in the Science and Its Use

Christine Youngblut

PREFACE

The Institute for Defense Analyses (IDA) prepared this document in partial fulfillment of the Central Research Program task titled “Climate Mitigation and Adaptation, An Integrated IDA Approach.” The research was conducted during the period March 2009-June 2009. The task was to update understanding about climate change science and activities to support its uses by policy and decision makers, sharing this knowledge among IDA staff members.

The author thanks the reviewers: Mr. Jason Dechant, Mr. Brendan Farrar-Foley, Dr. Forrest Frank, Dr. James Heagy, Dr. Terry Heuring, Mr. Mart Lidy, Dr. Jamie Link, Mr. Philip Meade, Dr. Margaret Myers, Mr. Zachary Rabold, and Gen. Larry Welch (Ret.) of IDA for their valuable comments.

Table of Contents

List of Figures

1. Introduction

1.1 Purpose

The U.S. is on the threshold of major changes in how it conducts climate change science research. These changes are being driven by several imperatives. One driving force is the growing recognition of the role that societal and ecological processes play in climate change. Another is the need to better support stakeholders who require climate-related information for the development of mitigation policy and adaptation activities.

Two additional factors make the current time particularly ripe for change. The National Research Council (NRC) has just reported on its second assessment of the U.S. Climate Change Science Program (CCSP) and recommends a major program restructuring, in large part to increase the engagement between the providers and users of climate information. The second factor is the wide expectation that the new administration will give new impetus to U.S. climate change research. White House attention is currently focused on setting policy to mitigate the future emission of greenhouse gases (GHGs). It is too soon to speculate on what changes the administration will engender in climate change science research, but we expect that significant attention will be paid to the NRC findings. A new consensus that climate change is progressing much more rapidly than projected just two years ago adds a sense of urgency to these topics (see, for example, Climate Congress (2009).

This paper presents a high level picture of this state of events and the key issues that have arisen. It is one in a series of papers looking at climate change issues. Others are expected to address climate change adaptation, human health concerns, and potential impacts on critical infrastructure. An additional paper summarizing major issues in the area of national and international security concerns is already available. The purpose of this series of papers is to raise awareness among policy and decision-makers of the full scope of climate-related concerns. By identifying the key issues, each paper identifies potential opportunities for, and impediments to, strengthening the U.S. response to climate change.

The nature of an issue paper such as this is that deficiencies and barriers to progress are highlighted; it is not our intent to slight the considerable and laudable progress that has been made in recent years. Instead, we hope that we can promote actions that will facilitate additional progress.

1.2 Structure of Paper

Sections 2 and 3 of this paper provide an overview of key issues in the development of climate change science, together with a review of the current state of the climate itself that establishes the importance of advancing our understanding. In the interests of brevity, these two sections assume some prior knowledge of the topics. Section 2 identifies a pair of climate change introductory texts for readers who wish additional background. Sections 4 and 5 look at issues surrounding the establishment of a national climate service and the proposal for a national initiative for climate-related decision support. The following section reviews often-stated concerns about the future of the nation's global observing systems and the urgent need to maintain and extend these capabilities. Section 7 looks at suggested restructurings of both U.S. climate change research and some of the major participants. The final section, Section 8, summarizes the key issues in terms of topics that are critical to continued development.

Appendix A provides a chronology of major recent events pertaining to the development of climate change science in the U.S. Links provide access to relevant information for those who wish further detail.

1.3 Sources of information

The information used in preparing this paper was obtained from recent assessments of climate change science, strategic planning documents, workshop and conference reports, relevant testimony from congressional hearings, and recent policy documents. Further inputs were gained from the Institute for Defense Analyses (IDA) staff members who brought the breadth of IDA's expertise to bear in identifying concerns and important actions.

2. The State of Climate Change Science

A large number of groups are engaged in climate change science research. The CCSP[1] has been the focal point of U.S. research for nearly a decade. Since its inception in 1988, the Intergovernmental Panel on Climate Change (IPCC) has been the primary group that assesses and reports on the worldwide state of climate change science. The IPCC does not conduct research but is the authoritative body for science assessments, as well as for projections of future climate change and their associated impacts.

In this section, we provide an overview of the capabilities of current climate change science and significant new research directions. This overview is structured around the core elements required to understand and project future climate changes: *GHG emissions scenarios* that are used to drive *climate models* to produce projections of the future climate, and *reanalysis and reconstruction of past climate data* that supports validating and refining climate models. (Global observing systems used to collect data about the present climate are discussed separately in Section 6.) The discussion assumes some knowledge of climate science so some readers may wish to review one of the following climate primers: the CCSP Climate Literacy, The Essential Principles of Climate Science and the NRC Understanding and Responding to Climate Change.

Climate change science is a maturing discipline that has made significant progress in recent years. The remaining gaps in our understanding are a major source of uncertainty[2] in climate change projections. It is important to note that the current omission or simplification of certain physical processes, interactions, and, in particular, feedback loops is widely believed to have resulted in *under-estimation* of future climate changes and their effects.

2.1 Climate Modeling

Climate modeling must support an increasingly diverse array of decision makers. Projections of earth system changes over centuries provide policy makers with information to make choices about large-scale mitigation and adaptation strategies. Those responsible for the management of ecosystems and critical societal infrastructures and resources need regional or local information on the decadal and seasonal time scales. Differences in temporal and spatial scales are also required for planning, monitoring, and responding to different types of extreme climatic and weather variations. In addition to supporting decision makers in all sectors of society, models must be capable of continuing to increase our knowledge of how physical systems and biogeochemical processes respond to direct and indirect GHG forcings.

Introducing multiple environmental stresses to understand the net impact of simultaneously occurring environmental modifications is a major challenge. Multiple stresses produce impacts that are more than simply additive and ongoing dynamic changes in the stresses and feedback effects raise the level of difficulty. There are no generally agreed upon methodologies for studying these types of complex systems (NRC 2007a).

Climate Models – These models are a mathematical representation of the physical and chemical processes occurring in the climate system. The goal of the most advanced models, coupled atmosphere-ocean general circulation models (AOGCMs) is to represent all the major atmospheric and ocean climate processes. Our lack of understanding of several key processes means that AOGCMs have limitations that are a major source of uncertainty in current climate projections.

The next generation of climate models is expected to resolve several critical deficiencies. They will include components capable of accurately simulating the carbon cycle, large ice sheets, atmospheric chemistry,

---

1 The CCSP was established in February 2002 by merging the U.S. Global Change Research Program (USGCRP) and the Climate Change Research Initiative (CCRI). The USGCRP was the first federally coordinated program that supported climate change research; it was established as a presidential initiative in 1988 and received congressional support under the Global Change Research Act in 1990. The CCRI was launched as a presidential initiative in 2001 to study areas of climate change science uncertainty and identify priority areas for investments.

2 Some uncertainty is unavoidable, even given a perfect understanding of climate processes. Sources of this type of uncertainty include future solar radiation and changes in anthropogenic emissions.

aerosols, and dynamic vegetation, as well as feedbacks from societal choices that further modify the systems (DoE 2008a). Such models are in the early stages of their evolution. Incremental progress will continue to be made, but a large gain increase in capability is unlikely within the next ten years. Difficulties in incorporating the global carbon cycle, for example, range from the difference in scale between human-induced changes and large natural fluxes to uncertainty about regional, seasonal, and interannual variations in the carbon cycle (CCSP 2008a). The magnitudes and distributions of terrestrial and ocean carbon sources and reservoirs are still uncertain, as are the processes controlling their dynamics (NRC 2007b). Models are also evolving toward finer resolutions that enable both incremental improvements (e.g., simulation of narrow boundary currents and the circulation in relatively small ocean basins) and fundamental improvements (e.g., direct simulation of dominant deep atmospheric convection circulations that reduce previous reliance on uncertain parameterizations). This research direction has its own challenges. Mesoscale[3] eddy-resolving ocean models, for example, require maintaining realistically small amounts of mixing across constant-density surfaces in the more turbulent flows to avoid distortion of the much slower thermohaline circulations (CCSP 2008a).

There are specific improvements that would help answer certain critical questions. One of particular societal interest is the rate and magnitude of future sea level rise due to rapid ice sheet melting; this requires the inclusion of fully dynamic ice sheet models and ocean/ice shelf interactions (ASAC-BERAC 2008). Some questions can only be addressed by shifts or changes in climate modeling paradigms. Accurate projections of changes in the local frequency of climate extremes, for example, require representing high-order moments in models primarily designed to predict low-order moments. Whereas characterizing abrupt[4] climate change requires models integrated over the full spectrum of forcing and parameterization uncertainties (ASAC-BERAC 2008).

Complementary research directions include (1) creating large model ensembles to better estimate the uncertainties of physical parameters (Murphy et al. 2007, Stainforth & Smith 2009); (2) validating initialization procedures through observational, experimental, and focused modeling activities; and (3) investigating how to leverage the insights and constraints of weather prediction to quantifying uncertainty in climate predictions (WCRP 2009a).

Regional Projections – AOGCMs typically use a coarse grid spacing (typically 2° x 2°) and do not resolve, for example, the small-scale variations in precipitation in mountainous regions that are critical to water management, nor do they resolve extreme events such as thunderstorms and tornadoes (WCRP 2008a). Fine resolution regional climate forecasts are needed both for decision makers and to investigate phenomena that affect regional climate change. Uncertainties in the small-scale details of external forcing and responses and a lack of knowledge on internal variability at small scales inhibit progress. The data necessary to both improve understanding of regional climate and to validate regional models is scarce, reflecting inadequate spatial and temporal coverage of observations, fragmented and of poor quality.

The regional forecasts are derived from global models using downscaling techniques and bias removal. Downscaling techniques are either statistical or dynamical approaches such as nested regional climate models (RCMs), variable resolution global models, and global uniform high-resolution time-slice simulations. Statistical methods are more computationally efficient but highly dependent on the accuracy of regional temperature, humidity, and circulation patterns produced by the parent global models. RCMs, the most widely used downscaling technique, employ higher resolution and better representation of important regional processes that improve the physical realism of the simulated climate. But RCMs are computationally demanding and deficiencies in the global models whose outputs drive the RCM lateral boundaries can severely degrade the usefulness of regional projections (CCSP 2008a). Even with regional models, the highest spatial resolutions are usually several tens of kilometers and techniques such as multiple nested grids are required to achieve spatial resolutions on the order of 50 kilometers. Careful evaluation is necessary to determine whether there are differences between the regional's large-scale circulation and its driving data set and, if so, whether there is a physical basis. Other limitations include difficulty in outflow regions of domains with relatively strong cross-boundary flow, dealing with unresolved scales of behavior,

---

3 Refers to regional or local phenomena.

4 The definition of an abrupt climate change is a transition to a new state at a rate determined by the climate system and faster than the cause (NRC 2002).

and a computational rate due to smaller time steps that limits the length of simulations. Further, regional models do not always capture regional trends in extreme events and it is difficult to distinguish between model failures and natural variability.

The North American Regional Climate Change Assessment Program illustrates the leading edge of research. This effort is investigating uncertainties in future climate projections on the regional level by matching RCMs with a basic spatial resolution of 50 km[5] of the U.S., Canada, and northern Mexico against AOGCMs. It will drive the RCMs with reanalyses (see Section 2.3 below) to further validate regional performance (Mearns 2009). The World Climate Research Programme (WCRP) (2009b) recently announced a Coordinated Regional climate Downscaling Experiment (CORDEX) to develop a framework for evaluating and improving regional climate downscaling techniques. CORDEX plans to produce a new set of regional climate downscaled-based projections for input to the IPCC Fifth Assessment Report.

Seasonal and Decadal Prediction – High quality seasonal predictions are available for a very limited set of regions and variables, primarily tropical Pacific sea surface temperature (WCRP 2008b). Model fidelity and forecast initialization continue to limit seasonal forecast quality, particularly for land surface temperature and rainfall. Advances in the fidelity in modeling land-atmosphere interactions are especially important for improving seasonal predictions. Other research is investigating the potential of coupled ocean-atmosphere data assimilation for improving model initializations (WCRP 2007). Approaches for downscaling and validation to cover the local space and time scales most of interest, for assessing the quality of seasonal prediction, and for improving the consistency and continuity of medium- and long-range information are additional areas of research (WCRP 2008b). Much of this work is impeded by the lack of seasonal-relevant climate observations.

A more recent endeavor, decadal predictions are being developed for the 10 to 30 year range (WCRP 2009a). Confidence is higher for assessments of changes in the North Pacific and North Atlantic regions than for other oceanic regions where a lack of data hinders estimating simulation quality (CCSP 2008a). Decadal predictions face similar challenges to seasonal predictions but must additionally take account of GHG forcings. Previous work indicates that the latter requires an increased ability to distinguish between natural and forced decadal variability and has revealed significant dynamical connections between, for example, the tropics/extratropics, Pacific/Atlantic basins, and ocean/land that require further investigation (Vimont & Solomon 2008). Examples of other research areas include assessing the predictive skill of state-of-the-art climate models initialized using data from ocean and atmospheric observations over recent decades (Hurrell 2008) and developing a framework for seamless prediction of weather and climate variations on timescales ranging from a season to a few decades (WCRP 2009a).

Incorporating Human Dimensions – Human dimensions research seeks to answer questions about the role of human actions and behavior in changing the climate and in mitigating and adapting to the impacts of climate change. It requires integrating earth system models with models that represent social and economic behaviors to explore the quantitative relationships between decision-making on mitigation and adaptation and to explore influences on the carbon cycle and other aspects of the environment (NRC 2007a). The integrated assessment models in practical use are relatively simple (CCSP 2008a).

Newly available geographically explicit data sets with global coverage and new computational techniques for modeling human systems on the global scale are bringing scientists closer to integrating changes in land use and the water cycle into assessments (Alcamo 2009). Progress in other areas requires a better understanding of the interactions and feedbacks among different components of the natural and social systems (NRC 2007a). Topics of particular interest include (1) environmentally significant consumption, (2) risk-related judgment and decision-making under uncertainty, (3) how social institutions affect resource use, and (4) socioeconomic change as context for climate change impacts and response, as well as (5) valuation of climate consequences and policy responses (Stern & Wilbanks 2009). The Integrated Global Systems Model (IGSM) is an example of leading research. Using an interacting set of computer models, the IGSM integrates climate science, technological change, economics, and social policy analysis into forecasts of the pressing issues in global change science and climate policy.

[5] Compared to the continental scale of AR4 models.

Research, data collection, and modeling socioeconomic and behavioral functions have lagged behind corresponding activities on the physical climate systems (NRC 2007a). There is a shortage of human systems data in suitable forms and problems in linking social and behavioral science disciplines to climate questions. It is important to model urban systems that represent a rapidly growing sector of human and environmental interactions and affect biophysical and biogeochemical interactions and feedbacks within the climate system. This requires a better understanding of the social processes that drive urban expansion (WCRP 2008a). A lack of suitable interdisciplinary training and a long recognized mismatch between the set of agencies that support climate change and those with strong capabilities in the social sciences are additional impediments (Stern & Wilbanks 2009).

Integrating Ecological processes – An understanding of how terrestrial ecosystems respond to climatic and atmospheric change is critical for both evaluating the net GHG balance between the Earth's surface and for supporting mitigation and adaptation decision-making. Recently developed AOGCMs that incorporate the carbon cycle show substantially different feedback between the physical climate system and carbon cycle. These models include natural ecosystems with some limitations, for example, lack of dynamic crop growth, and do not include such human-related activities as deforestation. Continuing the example above, the terrestrial component of the IGSM includes dynamically linked hydrologic and ecologic models in a Global Land System Framework; see Figure 1 (Schlosser 2007).

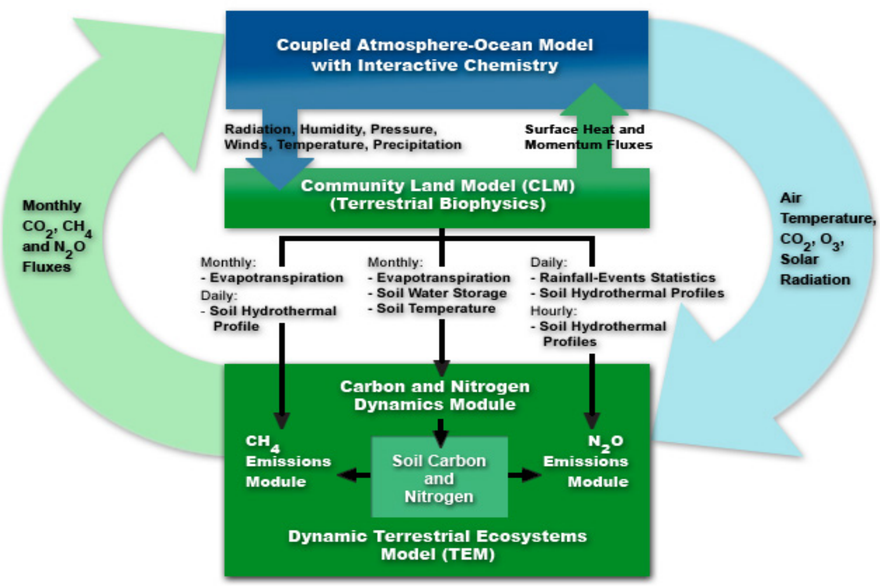

Figure 1. The Global Land System Framework[6]

Ecological response to climate-related changes is highly likely to be more difficult than climate to model accurately at local scales, because threshold and non-linear responses, lags and reversals, individualistic behaviors, and stochastic events are common (CCSP 2008b). Further, we are still learning about the level of complexity in the interactions among ecological and climate processes. Recent evidence, for example, suggests unexpected dynamics through interactions between physical, chemical, and biological processes within ecosystems (Heimann & Reichstein 2008). This raises questions about the extent to which climate and environmental factors, other than carbon dioxide (CO_2) and rising temperatures, might modify the carbon balance of the world's ecosystems. Improving our understanding of critical ecosystem processes requires advances in experimental ecological research and scientific synthesis across physical, biological, and social sciences (CCSP 2009a; DoE 2008b; NRC 2007a; USGS 2007)

The statistical and simulation ecosystem models that have supported resource management for many years are limited to a specific sector, geographical area, or even species. Integrated assessment models that enable more extensive investigations into ecosystem interactions are starting to emerge and may see practical use in the next few years (Murawski 2008).

Ecological forecasting would be another valuable tool for decision makers. The CCSP has developed a vision of ecological forecasting that allows the incorporation of observations, experimental results, process

6 This figure is taken from the MIT Joint Program on the Science and Policy of Global Change website.

studies, and modeling activities at a wide variety of scales ranging from molecular through regional and even global (CCSP 2009a).

Computing Challenges – Climate modeling requires extensive computational resources. Computers capable of speeds just over a petaflop are now available but increasing the resolution of models to 3–5 km and decadal-century scale integrations will require computers with the capability of about 10 petaflops by 2010 and 100 petaflops by 2025 (WCRP 2009a).[7] With a price tag in the hundreds of millions of dollars, these computers will be beyond the resources of most national centers and some fear that the result will be an international modeling center that diverts future investments from existing national centers. Associated challenges include a scalability requirement on very complex models to exploit petaflop computer systems, operating systems that enable model portability, and advanced optimizing software with related infrastructure requirements to provide the type of seamless modeling environment needed to support next generation multi-scale model development and process integration (ASAC-BERAC 2008). Systems, such as the Earth System Grid, that enable international data sharing of massive data sets will be vital.

2.2 GHG Emissions Scenarios

GHG emission scenarios generate the emission trajectories used as inputs to the climate models that provide projections on the future climate. The best-known scenarios are the Special Report on Emission Scenarios (SRES) used in the last two IPCC assessments (IPCC 2000). These are driven by assumptions about economic activity, rate of technological change, and demographic developments in different regions of the world that are themselves uncertain. Developed a decade later, the CCSP scenarios exploit advances in modeling economic and natural sciences, provide more complete coverage of GHGs, and used a multiple path development approach to facilitate insights into key assumptions (CCSP 2007a). Even so, the CCSP emission trajectories fall within the envelope of those generated by the SRES scenarios (CCSP 2008c).

Emissions scenarios are not used consistently across simulations or across applications such as impact and vulnerability assessments. This inconsistency inhibits urgently needed comparability among studies for different sectors, regions, and periods (WCRP 2008a). A set of international guidelines for applying a harmonized set of scenarios, including baselines and policy scenarios, is needed.

Many additional uses of emissions scenarios are possible. The ability to characterize the extent and severity of drought caused by changes in precipitation patterns, for example, would aid decision making about adaptation activities. These further uses are hindered by a lack of capacity to produce, disseminate, apply, evaluate, and adapt scenarios (CCSP 2007b).

There is an important lesson in the underestimation of recent GHG emissions by both the SRES and CCSP scenarios: scenario assumptions should be continually validated against new data to allow timely corrections and prevent unnecessary surprises. Mechanisms should be in place to automatically notify scenario users about significant changes and, whenever possible, the implications of those changes. The underestimation also highlights the importance of progress in the social sciences to understand human behavior and potential future climate forcing (NRC 2007b).

2.3 Analysis of Earth System Data & Climate Reconstruction

Past climate information is a critical resource in improving our understanding of climate change science and the primary tool for model validation. Further, increased availability and accuracy of climate data sets has the potential to refine estimates of climate sensitivity with a dramatic impact on the accuracy and usefulness of climate projections. Unfortunately, reanalysis is often not a one-time event. Data must be reprocessed as more becomes known about the properties of historic data and how to retrieve climate information from them (WCRP 2008a).

Widespread, reliable instrumental records are available for the last 150 years or so but data require reanalysis to resolve the short length or inhomogeneity of many data sets. The CCSP (2008d) has just completed a reanalysis of regional (North America) temperature, precipitation, and wind changes from the mid-1900s to present day with a spatial resolution on the order of 100 miles and a temporal resolution of 6–

[7] IBM is under contract with the Department of Energy to build a 20-petaflop Sequoia system scheduled for operational deployment in 2012.

12 hours. The World Meteorological Organization, NRC, CCSP, Global Climate Observing System, and others have increasingly called for a comprehensive program that engages multiple teams of scientists to develop and manage Climate Data Records (CDRs). The National Oceanic and Atmospheric Administration (NOAA) has more than 35 years of operational satellite data in its archives but there are significant challenges in exploiting this data collected by many disparate sensors and platforms (Karl 2009). Under funding in the 2009 American Recovery and Reinvestment Act, NOAA is taking a step in this direction and has begun a program to harvest mature technologies and apply them to develop CDRs from its archived satellite data. This work is focusing initially on environmental variables that comprise critical climate components, namely the water and energy cycles. NOAA's Comprehensive Large Array-data Stewardship System supports this work.

Two of the most significant outstanding challenges are (1) expanding reanalysis to encompass key trace atmospheric constituents and ocean, land, and sea ice and (2) improving estimates of uncertainty in reanalysis products (Trenberth 2008). Continued improvement depends on ongoing support for the underlying research, the development of comprehensive Earth system models to expand the scope of reanalysis, and the infrastructure for data handling and processes (WCRP 2008c).

Scientists must use proxy evidence (primarily from tree rings, corals, ocean and lake sediments, cave deposits, fossils, ice cores, borehole temperatures, glacier length records, and geologic data) to produce quantitative reconstructions of surface temperatures prior to the late 1800s. Problems in the availability and quality of proxy records increase moving backwards in time. Inconsistencies in past processing of the data pose additional problems. As a result, there are fewer than 30 annually resolved proxy time series available from A.D. 1000 to the present time and the majority of these are for the Northern Hemisphere. The NRC (2006) reconstruction of global surface temperature back 2,000 years is another major accomplishment that serves as an exemplar for future work.

Reanalysis and reconstruction activities would reap substantial benefits from increased international cooperation and a common research agenda could speed resolution of key climate uncertainties. At a minimum, there is a critical need for common data stewardship and sharing standards.

3. The State of the Climate: Changes since the IPCC AR4

We assess the state of the climate against the projections given in the IPCC AR4 based on recent GHG emissions. We then look at what recent climate data imply with respect to abrupt climate changes and dangerous anthropogenic interference (DAI).

The AR4 used a set of six emissions scenarios for climate modeling purposes but many of the projections are only reported for the emissions scenarios shown in **Figure 2**. The B1 scenario assumes low population growth and global solutions to economic, social, and environmental sustainability, including improved equity. The A1B and A1F1 emission trajectories are based on a population that peaks at mid-century, rapid economic growth, and the introduction of more efficient technologies; the A1B scenario additionally assumes a balanced use of all energy sources, whereas A1F1 (the "worst-case") is fossil fuel intensive.

	2050	2100
B1—Low emissions scenario:		
CO_2, fossil fuels	**11.7** (8.5- 17.5)	**5.2** (3.3- 7.9)
CO_2, land use	**-0.4** (- 0.7- 0.8)	**-1.0** (- 2.6- 0.1)
A1B—Medium emissions scenario:		
CO_2, fossil fuels	**16.0** (12.7- 25.7)	**13.1** (13.1- 17.9)
CO_2, land use	**0.4** (0.0- 1.0)	**0.4** (- 2.0- 2.2)
A1F1—High emissions scenario:		
CO_2, fossil fuels	**23.1** (20.6-26.8)	**30.3** (30.3-36.8)
CO_2, land use	**0.8** (0.0- 0.8)	**-2** (- 2.1- 0.0)

Figure 2. Carbon Emissions (in GtC/yr) for the SRES Scenarios used in Developing IPCC AR4 Projections[8]

Recent data indicate that the rate of GHG emissions continues to increase in most developed countries, despite reduction commitments made under the Kyoto Protocol (Johnson 2008; Woodward 2007). Although the U.S. has a stated goal[9] of reducing GHG emissions per unit of its gross domestic product 18%, by 2012 overall emissions have risen by 17.1% from 1990 to 2007 (EPA 2009).

The rate of emissions is increasing even more rapidly in developing countries. Emissions from these countries are expected to overtake those of developed countries by 2015 (EPA 2006). It is difficult to see how these trends will substantially change when the world energy demand is expected to grow by 45% from 2006 to 2030 and fossil fuels to account for around 80% of the world's primary energy mix. This implies a 45% increase in energy-related GHG emissions, to 41 gigatonnes per year (IEA 2008). Three-quarters of the projected increase in energy-related CO_2 emissions is attributed to industrial increases in China, India, and the Middle East, and 97% to non-OECD countries as a whole.

In March of this year, more than 2,000 participants from around 80 countries held a Climate Congress: Global Risks, Challenges and Decisions to update the knowledge on climate change that was compiled in the IPCC AR4. Although the synthesis report will not be available until June 2009, the Climate Congress (2009) has released six key messages. With respect to climatic trends:

> "*Recent observations confirm that, given high rates of observed emissions, the worst-case IPCC scenario trajectories (or even worse) are being realised. For many key parameters, the climate system is already moving beyond the patterns of natural variability within which our society and economy have developed and thrived…There is a significant risk that many of the trends will accelerate, leading to an increasing risk of abrupt or irreversible climatic shifts.*"

The IPCC AR4 best estimate of projected surface temperature increase during the 21st century for the "worst-case" A1F1 emission scenario is 4.0°C (likely range is 2.4°C to 6.4°C).[10] It is important to realize that many decisions to this point have been based on the IPCC AR4 mid-range projections: decisions that may now be invalid. We urgently need a new set of best-case, mid-range, and worst-case projections based on

---

8 This figure only references CO_2 but the SRES emissions scenarios include nitrous oxide, methane, halocarbon gas concentrations, ozone, water vapor, and aerosols.

9 In The *Global Climate Change Policy Book, Details of U.S. initiative* announced 14 February 2002.

10 The IPCC AR4 low-range (B1) projected temperature increase is 1.8°C (likely range 1.1°C to 2.9°C) and the mid-range (A1B) is an increase of 2.8°C (likely range 1.7°C to 4.4°C).

the current reality but the IPCC fifth assessment is not expected before 2014.

The AR4 used climate data collected up until 2005. Subsequent data imply that changes are occurring at a rate faster than predicted.[11] Following the lead of the European Commission, there is wide acceptance that temperature increases must not exceed 2°C of warming from preindustrial levels (Mann 2009, Oxfam 2007, Tirpak 2005).[12,13] Although this is a policy issue and beyond the scope of this paper, it is worth noting that many scientists fear that the 2°C safety margin will not be achieved (Bows 2009, Meinshausen 2005, Parry et al. 2008, Princiotta 2008, Ramanthan & Feng 2008, van Vuuren 2008, Weaver et al. 2007). The NRC (2009ba) warns recent emissions indicate that a warming in excess of 3°C is possible by 2100. Oxford University (U.K.) has just announced a conference to assess the consequences of a change in global temperature above 4°C. The implications of such increases for commonly discussed examples of abrupt climate change are illustrated in Figure 3.

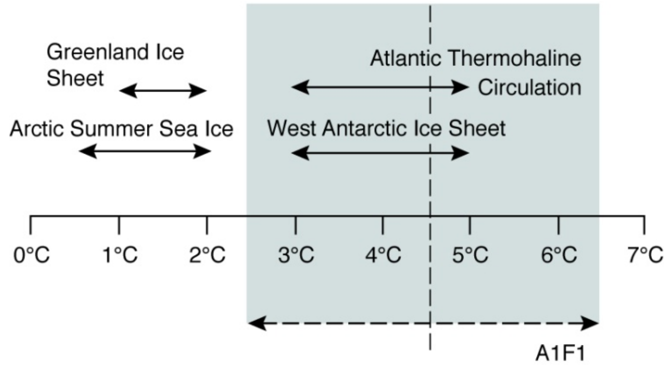

Figure 3. Abrupt Change for Global Temperature Increase

Based on data developed through literature review, an international workshop, & expert elicitation; Lenton (2008).

A massive release of methane from thawing peatlands, subsea hydrates and clathrates; collapse of the Atlantic Thermohaline Circulation; and loss of the Greenland and Antarctic Ice Sheets would each either activate strong amplifying feedbacks that would accelerate further climate change or result in global physical changes with major impacts on human society. There is growing consensus that we have already crossed the threshold to ensuring permanent loss of the Arctic summer sea ice, another example of abrupt climate change (Eisenman 2009, Lenton 2008, NSIDC 2007, Serreze & Stroeve 2008, Stroeve et al. 2007). Estimates on when the summer Arctic sea ice will disappear increasingly favor 2050 or earlier (NSIDC FAQ, Smedsrud et al. 2008, University of Washington 2009, Wang & Overland 2009). There is evidence of permafrost thawing throughout the Northern Hemisphere (USARC 2003) and ongoing release of methane (NOAA 2008, New Scientist 2005, UNEP 2008). Recent data suggest that the Thermohaline Circulation is already weakening (ACIA 2004, Bryden et al. 2005, Kuhlbrodt et al. 2007, Häkkinen and Rhines 2004). Data also show increasing loss of mass in the Greenland Ice Sheet, West Antarctica, and the Antarctic Peninsula (NSIDC 2009, Rignot et al. 2008, Mann 2009). We are gaining a better understanding of the processes that are speeding this loss but key uncertainties remain (Hare 2008, Naish 2009, Truffer & Fahnestock 2007). Many scientists are now projecting that the accelerated rate at which glacier melt water is reaching the oceans, combined with the effects of thermal expansion, may raise sea levels by 1m before 2100 (Carlson 2008, Climate Congress 2009, Mann 2009, NASA 2006).

The relatively short timescales involved in monitoring recent changes makes it difficult to distinguish the effect of natural variations in the climate from responses to anthropogenic forcing. However, the growing trend in rapid changes is cause for concern. There is an urgent need for committed and sustained monitoring of those processes that are particularly vulnerable to abrupt climate change (CCSP 2008e). The relatively short timescales involved in monitoring recent changes makes it difficult to distinguish the effect of natural

---

11 For examples of important data not included in IPCC AR4 see Chapin et al. (2005), Christoffersen and Hambrey (2006), Lenton et al. (2008), Lucas et al. (2007), NSF (2007), Rahmstorf et al. (2009, 2007), Rignot and Kanagaratnam (2006), Shephard and Wingham (2007), Stroeve et al. (2007), Wentz et al. (2007), and Zwally et al. (2005).

12 Tol (2005) describes how the European Commission came to settle on 2°C and reviews the validity of this selection.

13 A group of respected scientists from NASA, Columbia University, Yale, Massachusetts Institute of Technology, Lawrence Berkeley National Laboratory, Argonne National Laboratory, and several other institutions present evidence that global warming of more than 1°C above the level in 2000 has effects that may be highly disruptive (Hansen et al. 2007).

variations in the climate from responses to anthropogenic forcing. However, the growing trend in rapid changes is cause for concern. There is an urgent need for committed and sustained monitoring of those processes that are particularly vulnerable to abrupt climate change (CCSP 2008e).

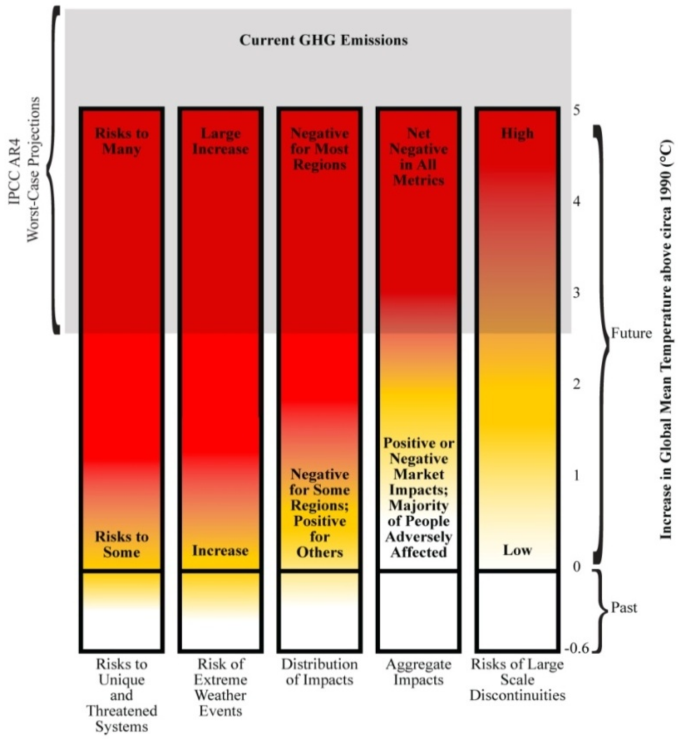

Figure 4. Reasons for Concern Updated & with New Data[14]

Climate change consequences are plotted against increases in global mean temperature (°C) after 1990. Each column corresponds to a specific RFC and represents additional outcomes associated with increasing global mean temperature. The color scheme represents progressively increasing levels of risk and should not be interpreted as representing ''dangerous anthropogenic interference,'' which is a value judgment.

The undefined term 'dangerous anthropogenic interference' (DAI) is generally used to include the consideration of societal and ecological impacts with purely physical ones.[15] In an effort to provide some insight into climate impacts that might be considered DAI, the IPCC's Third Assessment Report (2001) introduced what has become known as the "burning embers diagram." Smith et al. (2009) recently used the improved understanding of sensitivities and vulnerabilities presented in the AR4 to update this diagram; Figure 4 shows this updated diagram amended with an overlay that represents the consensus reported by the Climate Congress.

The points made above, as with most of the IPCC projections, considered climate change up to 2100. Temperatures are expected to continue rising after that point, with increasingly severe consequences. Another important point is that the lifetime of CO_2 concentrations in the atmosphere is not well understood, but climate change due to increases in CO_2 concentration is largely irreversible for the next 1,000 years even if all emissions were to (hypothetically) cease (Matthews et al. 2008, Solomon et al. 2008, Tyrrell et al. 2007).

14 Based on Fig 1 in Smith et al. (2009).

15 Article 2 of the United Nations Framework Convention on Climate Change (UN 1992) commits signatory nations to stabilizing greenhouse gas concentrations in the atmosphere at a level that ''would prevent dangerous anthropogenic interference (DAI) with the climate system.''

4. Providing Climate Services

Users of climate information can increasingly be found at all levels of society, from federal government to members of the general public seeking to make climate-informed decisions. There are growing calls for a national climate service that connects climate science to the stakeholders who need climate data, information, and knowledge to inform decision-making. Such a service would identify, produce, and deliver authoritative and timely information about climate variations and trends and their impacts (Miles 2006, NRC 2009a).

The concept of a national climate service is not new. In the mid 1990s, the CCSP began a prototype program to provide regional climate services.[16] Implemented by NOAA, Regional Integrated Sciences and Assessments (RISA) Program started with university-based efforts in regions where recent advances in integrated climate sciences held the greatest promise to assist decision-making. Highly successful, each of the RISA projects comprises experts from the biophysical and societal sciences who work with regional and/or local stakeholders to address important climate impact issues and information needs in their area. To date, the research has focused on the fisheries, water, wildfire, and agriculture sectors, as well as climate-sensitive public health and coastal restoration issues. The regions supported are shown in Figure 5. In its revised research plan, the CCSP (2008f) reports that a new RISA will focus on drought. A complementary Sectoral Applications Research Program (SARP) aids decision makers in the coastal and water resource management sectors. Other federal agencies, as well as some state and local groups, also have programs that provide climate information to decision makers (GAO 2009a; Pew 2009).

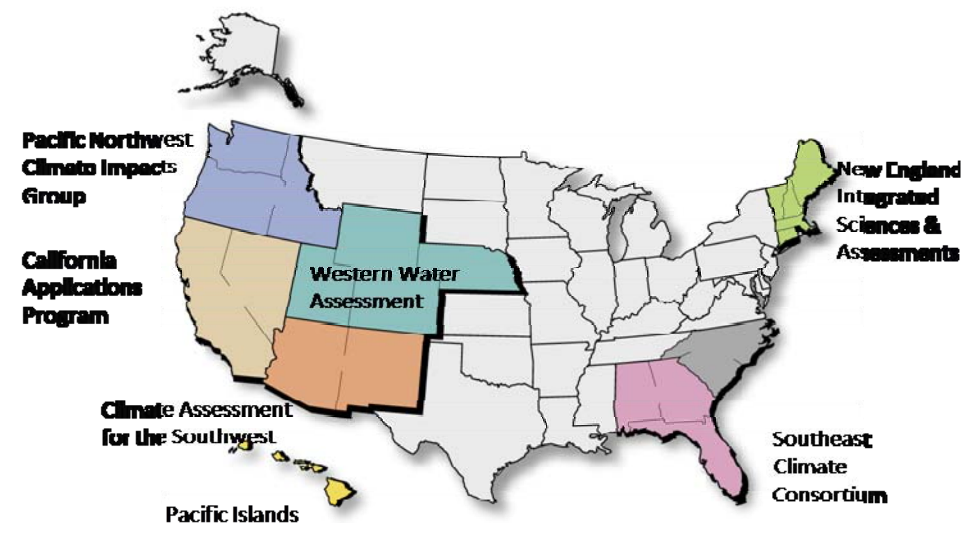

Figure 5. Current NOAA RISAs[17]

As a group, these programs provide important services, but only in selected regions or specific sectors. There is no single point of entry to the services and no group that serves national needs related to enhancing economic growth, managing risk and protecting life and property, and promoting national environmental stewardship. In 2000, the NRC (2001) reviewed the status of U.S. climate services and identified the importance of promoting a more user-centric climate service, one that reflected the value of historical and predictive knowledge, and promoted active stewardship of climate information. The NRC recommendations focused on enhancing the capabilities of the existing institutions and agencies, instead of building a national climate service from the ground up. This approach had the expected advantage of allowing quick implementation to enable large dividends at modest cost, but no actions were taken.

[16] The National Climate Program Act of 1978 included provisions that led to NOAA's National Climatic Data Center building a network of six Regional Climate Centers. Modeled after weather services, these centers were the precursor to the concept of a national climate service.

[17] Adapted from a figure in Building Bridges between Climate Science and Society.

In 2008, NOAA developed a draft strategic plan for a national climate service and independent Tiger Teams were asked to evaluate four alternative development strategies. These options were: (1) a national climate service federation, (2) a non-profit corporation with federal sponsorship, (3) a national climate service with NOAA as the lead agency and specifically defined partners, and (4) a NOAA weather and climate service developed from expanded and improved weather services. Each option has significant strengths and weaknesses, but none were viewed as ideal (NOAA 2009). The Tiger Teams did, however, identify some prerequisites to a successful strategy for developing a national climate service. First, NOAA needs to reorganize itself to enable greater connectivity of weather and climate functions. Secondly, the federal agencies need to collaboratively define their role and level of commitment in a national climate service. There must also be a lead federal entity.

In May 2009, the H.R. 2407: National Climate Service Act of 2009 was introduced in Congress.[18] This bill proposes establishing a National Climate Service at NOAA. This National Climate Service will serve three primary purposes (1) advance understanding of climate variability, (2) provide forecasts, warnings, and other information to the public, and (3) support development of adaptation and response plans by Federal agencies, State, local, and tribal governments, the private sector, and the public. The Under Secretary of Commerce for Oceans and Atmosphere will operate the service through a national center (the Climate Service Office) and a network of regional, state, and local outlets. The Under Secretary will maintain the networks of Regional Climate Centers and RISAs, defining their role in the service. Core elements include:

- Conducting analyses, studies, research, and observations relating to the effects of weather and climate on the public;
- Carrying out observations, data collection, and monitoring of weather and climate;
- Providing information and technical support for Federal agencies, regional State, tribal, and local government efforts to produce adaptation and response plans;
- Developing systems for management and dissemination of data, information, and assessments; and
- Conducting research to improve understanding of climate and to improve climate services.

To this end, the proposed bill directs the Under Secretary to utilize the assets and expertise of other offices and programs at NOAA that produce relevant information or products, including the National Weather Service, the National Environmental Data and Information Service, and the National Integrated Drought Information System. In June, Congress added $100 million to NOAA's 2010 budget for a variety of ongoing climate research programs – reportedly to speed the creation of the National Climate Service.[19]

A second bill, H.R. 2685: National Climate Enterprise Act of 2009, was introduced in June specifying how the service should be organized. In particular, this second bill establishes an Interdepartmental Oversight Board, chaired by the White House Office of Science and Technology Policy (OSTP), which would set priorities and develop a cross-agency budget. H.R. 2407 meets the Tiger Team's prerequisite of a lead federal entity and the Interdepartmental Oversight Board required under H.R. 2685 gives a mechanism for federal agencies to collaboratively define their role and level of commitment. There is no news of any reorganization within NOAA directed at enabling greater connection between weather and climate functions.

The functions and roles of a national climate service that supports decision-making on domestic concerns are well defined. Insufficient attention has been paid to serving the needs of those federal agencies heavily involved in overseas activities, such as the Department of Defense, the Department of State, and the U.S. Agency for international Development. Questions also remain on how best to facilitate cooperation between a U.S. national climate service and non-domestic providers of climate information such as the World Meteorological Organization (WMO) World Climate Applications and Services Programme (WCASP)/ Climate Information and Prediction Services (CLIPS). A goal of the 2009 WMO World Conference-3 is to establish an international framework to guide the development of climate services that will link science-based climate prediction and information with climate risk management throughout the world.

18 As of June 18, the latest action on H.R. 2407: The House Committee on Science and Technology recommended the bill for consideration by the House as a whole (June 3). House Speaker Nancy Pelosi has told the chairs of relevant House committees to finish their review by June 19. No date has been set for a vote.

19 Science, News of the Week, 12 June 2009 at: http://www.sciencemag.org/cgi/content/summary/324/5933/1372.

5. Support for Decision-making

Even given a National Climate Service such as discussed in Section 4, climate-related decision-making poses several challenges. Many of the decisions exhibit the characteristics of 'wicked problems': multidimensionality, scientific uncertainty, value conflict and uncertainty, mistrust, and urgency (Dietz & Stern 1998). For example, the effects of climate change vary by region, ecology, and a range of societal factors, and areas of concern rarely map to the responsibilities of human organizations. Decision makers cannot rely on stability of historical patterns to guide future actions and decisions will need frequent adjustments to changing circumstances and societal needs. Decisions require a longer-term view than usual, making it necessary to expect and prepare for "surprises." Many will be made in a decentralized fashion, requiring coordination at national, state, and local levels. Decision practices and routines that worked in the past are unlikely to remain effective. Moreover, decision makers must recognize that change will be constant and their practices and routines must be adaptable to evolve with the climate and with changes in social and economic conditions (NRC 2009b).

Decision support services—the activities, consultations, or other forms of interactions that enable decision makers to make better use of decision-relevant information and decision support products, educate those involved, and facilitate or evaluate the decision support processes.

Decision support products—the tangible deliverables developed in the course of decision support (e.g., data, maps, projections, images, tools, models, and documents) and that contain information intended to be useful for decision-making.

Decision support systems—comprise the individuals, organizations, communication networks, and supporting institutional structures that provide and use decision support products and services.

Figure 6. A Broad Concept of Decision Support

The NRC (2009b) recently undertook a task "to provide a framework and a set of strategies and methods for organizing and evaluating decision support activities related to climate change." The NRC advises that climate-related decisions require a broad view of decision support, that is, a set of processes that create the conditions for the production of decision-relevant information and its appropriate use, see Figure 6. Ongoing communication between the producers and users of information is at the center of these processes. There is a shift in focus away from providing tools or support and toward supporting users' practices (NRC 2007c).

One of the NRC's major recommendations is that the federal government undertakes a climate-related decision support national initiative with two main thrusts. A *service element* would support and catalyze processes to inform climate-related decisions. It would use, for example, demonstrations and development activities to (1) promote the emergence of effective decision support systems, (2) support networks to link decision support activities and facilitate learning among them, and (3) help nonfederal actors develop decision support systems. A *research element* would be responsible for developing the science of climate response to inform decisions and promote systematic improvement of decision support processes and products in all relevant sectors of society. The key research areas for developing the information needed *for* decision-making and for research *on* decision-making are shown in Figure 7.

Although the initiative can be pursued under the authority of the Global Change Research Act of 1990, the suggested changes in how federal agencies serve their constituencies, coordinate with each other and nonfederal decision makers, and set research priorities necessitate a reformulation of how the Act is implemented. The panel does not believe that the initiative should be centralized in a single agency; doing so could disrupt existing relationships between agencies and their constituencies, as well as formalize a separation between the emerging science of climate response and fundamental research on climate and the associated biological, social, and economic phenomena. There is considerable overlap between the goals of such an initiative and a National Climate Service but the extent and manner in which the former might be integrated into the latter requires carefully consideration.

NOAA's RISA, SARP[20], and International Research Institute for Climate and Society[21] and the EPA's Global

[20] The NRC (2007c) recommends that SARP "support research to identify and foster innovations needed to make information about climate variability and change more usable in specific sectors, including research on the processes that influence success or failure in the creation of knowledge-action networks for making climate information useful for decision making."

For Decision-making	*On* Decision-making
▪ Understanding climate change vulnerabilities: human development scenarios for potentially affected regions, populations, and sectors. ▪ Understanding the potential for mitigation, including anthropogenic-driving forces, capacities for change, possible limits of change, and consequences of mitigation options. ▪ Understanding adaptation contexts and capacities, including possible limits of change and consequences of various adaptive responses. ▪ Understanding how mitigation and adaptation interact with each other and with climatic and ecological changes in determining human system risks. ▪ Understanding and taking advantage of emerging opportunities associated with climate variability and change.	▪ Understanding information needs. ▪ Characterizing and understanding climate risk and uncertainty. ▪ Understanding and improving processes related to decision support, including decision support processes and networks and methods for structuring decisions. ▪ Developing and disseminating decision support products. ▪ Assessing decision support "experiments."

Figure 7. Decision Support Research Areas

Change Research Program already embody many of the principles of effective decision support systems. Programs like these should be expanded and used as models by federal agencies establishing their own decision support programs. There are also insights to be gained from CCSP's experiment in connecting climate research to decision-making for water resource management (CCSP 2008g).

The Transition of Research Applications to Climate Services (TRACS) Program[22], another NOAA program, the transitions experimentally mature climate information tools, methods, and processes from research into operational settings. TRACS accommodates transition project partnerships within NOAA units, between external partners and NOAA, and among external partners. The Adaptation Learning Mechanism, implemented by the United Nations Development Programme, the World Bank and the United Nations Environment Programme, is a knowledge-sharing platform that provides a nascent inventory of internationally available tools.

In addition to insights and expertise available from these efforts, guidance may be obtained from recent evaluations of the use of science-based assessments in decision-making (NRC 2005), the uses of Earth science information in decision support activities (CCSP 2008h), and how to characterize, communicate and work with uncertainty (CCSP 2009b).

As envisioned, the initiative's scope crosses all climate-related endeavors, government and nongovernment, and assuring effective multi-organizational collaboration will be a significant challenge. Institutional, organizational, cultural, and professional education and training barriers would have to be overcome and the inertia in government systems could impede rapid progress. High-level federal leadership would be an essential prerequisite.

The federal government would have to assume certain functional roles within the initiative. These include providing decision support services and products to other climate-affected constituencies who lack information they need, and serving any public goods that would not otherwise be met. Additionally, government support is needed to enable scientists to build their capacity to work as researchers and advisors to those charged with making climate-related decisions (NRC 2009a, NRC 2007d).

Meanwhile, in 2008, the International Research Institute for Climate and Society (IRI) in partnership with the Center for International Earth Science Information Network and the Mailman School of Public Health initiated a Climate Information for Public Health Summer Institute. This annual two-week workshop offers public health decision-makers and their partners the opportunity to learn practical methods for integrating climate knowledge and information into decision making processes through expert lectures, special seminars, focused discussions, and practical exercises. Responding to a lack of academic or practitioner text, tools, methods, and data, the Summer Institute curricula is designed to facilitate participants refining and delivering

---

21 A cooperative agreement between NOAA's Climate Program Office and Columbia University's Earth Institute.

22 RISA, SARP, and TRACS are part of NOAA's Regional Decision Support Program.

the materials in their own communities.

An effort by the National Academy of Sciences, through its NRC, is tackling the other side of the coin, providing guidance to the scientific community. Established in October 2008, the Committee on Climate, Energy, and National Security will facilitate the increased involvement of scientists in answering questions related to climate and environmental change, energy, natural disasters, and national security.[23] During its two-year duration, it will be a source of strategic guidance to national security-related climate change, environmental science, and natural disaster research conducted as part of the federal sponsor's global climate change research activities.

[23] See the project's web page at: http://www8.nationalacademies.org/cp/projectview.aspx?key=49017.

6. Maintaining Global Observations

Long-term, sustained Earth system observations are the foundation upon which Earth science is developed. They provide the yardstick against which climate models are both validated and refined. Among many crucial data, baseline inventories of terrestrial carbon sources and reservoirs and measurements of the amount of GHGs in the atmosphere are urgent needs at the current time. [24] Measuring the successfulness of mitigation policies and monitoring compliance will also rely on observational data (Gallagher 2009).

There is no comprehensive U.S. system that is specifically designed to observe climate change and climate variability. Sustained observing systems provide data principally for non-climatic purposes, such as predicting weather, advising the public, and managing resources. U.S. observations of climate change are based upon a combination of operational and research programs that include NASA, NOAA, and the U.S. Geological Survey (USGS) Earth-observing satellites and extensive non-satellite observational capabilities. Working in partnership with other nations is a central precept of the U.S. global climate observation strategy. Since 2002, the U.S. has entered into a number of important bilateral climate agreements, funding projects with Australia, China, New Zealand, South Africa, and South Korea (CCSP 2008i).

The U.S. space-based observing capabilities are diminishing through program cancellations and cutbacks and the deterioration of existing capabilities over time as shown in Figure 8 (NRC 2007e). This loss of existing and planned satellite sensors may be the biggest threat facing the CCSP (NRC 2007b).

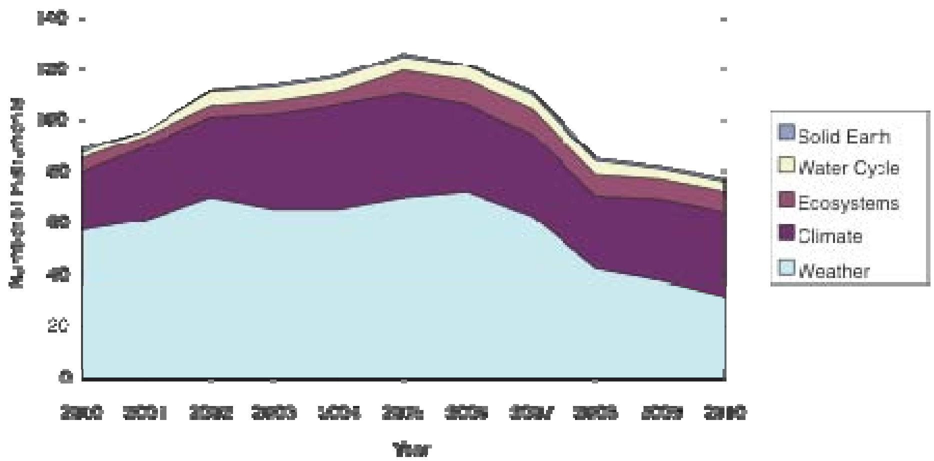

Figure 8. Number of U.S. Space-Based Earth Observation Instruments 2000 – 2010 (NRC 2007e, Figure ES.2)

As well as maintaining current capability, future observational continuity must be enhanced and new categories of data collected. The best-known assessment of observational needs for the coming decade is the Decadal Survey. This work considered contribution to important scientific questions facing earth sciences today. It also considered contribution to applications and policymaking and took account of multi-discipline issues in climate change, water resources, ecosystem health, human health, solid-Earth natural hazards, and weather (NRC 2007e). The resulting set of 17 missions is designed to provide a program that is robust to the removal or delay of any one mission and, at the same time, enable augmentation or enhancement should funding permit. The program is consistent with the recommendations from the USGCRP, CCSP, and the U.S. component of the Global Earth Observation System of Systems (GEOSS).[25] The NRC Committee on Strategic Advice on the U.S. Climate Change Science Program identified an additional priority need: improved temporal, global moderate resolution land surface observations (NRC 2009b). There is wide endorsement of the Decadal Survey's recommendation (UCAR 2008) but budget

[24] In February, NASA's attempt to launch the Orbiting Carbon Observatory was unsuccessful. This was the first U.S. spacecraft dedicated to studying atmospheric CO_2 and complete global mapping of CO_2 sources and sinks.

[25] The U.S. is an active participant in the Intergovernmental Group on Earth Observations and GEOSS development. The U.S. also supports several international observational and monitoring activities, including: the Global Climate Observing System; the Global Ocean Observing System; the Global Geodetic Observing System; and the Global Terrestrial Observing System. All of these are contributing systems to the GEOSS. A recent GAO (2009b) report reviews NOAA's progress in the GEOS-R acquisition.

projections and the increasing scope and cost of the Tier 1 decadal survey missions indicate that the first phase of the survey missions cannot be completed in the specified timeframe and important continuity will be lost (Anthes 2009).

Satellite and non-satellite instruments have different temporal, spatial, and phenomenal characteristics. Both types of data are needed to calibrate and validate each other. Critical surface-based and upper-air atmospheric sounding networks should be sustained and enhanced as necessary to satisfy climate and other Earth science needs. Airborne platforms have also suffered substantial diminution and should be restored and unmanned aerial vehicles should be increasingly factored into future planning (NRC 2007e).

Detailed meteorological observations on a local and regional scale are important for improved regional climate monitoring, in addition to traditional applications such as forecasting high-impact weather. Ground-based mesoscale meteorological observations in the U.S. are driven largely by local needs, with observations being collected by a range of small businesses, large corporations, state and local agencies, and others. An overarching national strategy is needed to integrate local observations and define the additional observations required to achieve a multi-purpose national “network of networks” (NRC 2008). Necessary precursor activities include bringing together stakeholders from the various sectors to determine common needs, setting standards for the network, and identifying a centralized authority to provide core services. The NRC recommends that the U.S. establishes a publicly chartered, private non-profit corporation to administer the network of networks, with the goal of encouraging the leadership of pivotal federal agencies such as NOAA while protecting, facilitating, and enabling the role of other interests in the collaborative enterprise. The NRC also provides recommendations on the numbers and types of some measurements that meet national needs, for example, a network of soil moisture and temperature observations deployed nationwide at approximately 3,000 sites.

Observations of physical Earth systems and processes are insufficient to develop the next generation of integrated climate models. Informing decisions for a changing climate will depend on site-specific and relevant baselines of environmental, social, and economic information against which past and current decisions can be monitored, assessed, and changed. There is a shortage of reliable and consistent data on the interactions among climate, humans, and environmental systems. This information is often unavailable or absent in the less developed regions of the world and privacy restrictions can limit its availability in many developed countries. There is a particular need for time-series data related to human pressures on the environment and data on human exposure, sensitivities, and responses to global environmental change (NRC 2009a). A decadal survey process focused on societal issues could be a useful approach to identifying climate observations priorities for ground (land and ocean) measurement systems and data on the human dimensions of climate change (NRC 2009a).

Fundamental improvements are needed in connecting (1) the raw observations that produce information; (2) the analyses, forecasts, and models that provide timely and coherent syntheses of otherwise disparate information; and (3) the decision processes that use those analyses and forecasts to produce actions with direct societal benefits (NRC 2007e).

7. Restructuring Climate Change Science

The last year has seen several recommendations for functional restructuring of climate change science and for organizational restructuring among the community. We start with the NRC (2009a) proposed restructuring of the CCSP.

The CCSP has made significant advances in many areas of climate change science. The two major weaknesses have been a lack of attention on the human dimensions of climate change[26] and poor progress in engaging stakeholders and communicating science results (NRC 2007b). The NRC recommends restructuring the program to "become more cross disciplinary, more fully embrace the human dimensions component, and encourage an end-to-end approach (from basic research to decision support)" and to help the participating agencies better integrate their programs. The NRC's key action priorities for restructuring the CCSP are listed in Figure 9.

1. Reorganize the program around integrated scientific-societal issues.
2. Establish a U.S. climate observing system, defined as including physical, biological, and social observations.
3. Develop the science base and infrastructure capable of modeling regional weather and climate, seasonal-to-decadal time frames, and environmental and human systems.
4. Strengthen research on adaptation, mitigation, and vulnerability.
5. Initiate a national assessment process with broad stakeholder participation to determine the risks and costs of climate change impacts on the U.S. and to evaluate response options.
6. Coordinate federal efforts to provide climate services routinely to decision makers.

Figure 9. Action Priorities for Restructuring the CCSP

The functional architecture of the restructured program is shown in **Figure 10**. Each component in this architecture represents an expansion of the existing CCSP but it is their integration that requires the most careful consideration and planning. Stakeholders at the federal, state, and local government levels are explicitly included in the revised scope, as well as partnerships with nongovernmental organizations, private companies and foundations, and individuals. In the past, misalignments among CCSP priorities and those of the thirteen participating agencies resulting in some needed research being unfunded. Coordinating activities among those agencies carried a high administrative burden. These problems will be compounded when the list of participating agencies expands adding new research directions and increased stakeholder participation. There are also outstanding questions. For example, how will limited researcher and decision support resources be allocated across stakeholders? Who will adjudicate competing research needs?

Many important physical processes remain ill defined and require continued research. Research into ecological and human dimensions areas must not be conducted at the expense of this foundational research. Additionally, there are still benefits to be gained by having different groups of scientists investigate the same topic. For example, there are four major U.S. centers of climate modeling[27] and experience has shown (1) that an average across several models outperforms a single model, (2) competition between groups spawns creative innovation, (3) modeling groups can take very different and equally important approaches, and (4) having multiple models and entry points permits more people to participate in model development (UCAR 2008).

The CCSP agencies currently lack experience in the human dimensions of climate change. The NRC suggests that an agency devoted to basic and applied social science research, such as the National Science Foundation (NSF), will be needed to build the human science research capacity. Another danger is a possible fragmenting of the research community that results from simultaneously increasing the breadth and depth of areas of investigation or as different research groups become more focused on particular specific stakeholder needs.

---

[26] Spending on human dimensions research has never exceeded 3% of the research budget (NRC 2007b).

[27] NSF's National Center for Atmospheric Research, NOAA's Geophysical Fluid Dynamics Lab, NASA's Goddard Institute for Space Studies, and Department of Energy lab contributions to both climate modeling and computing.

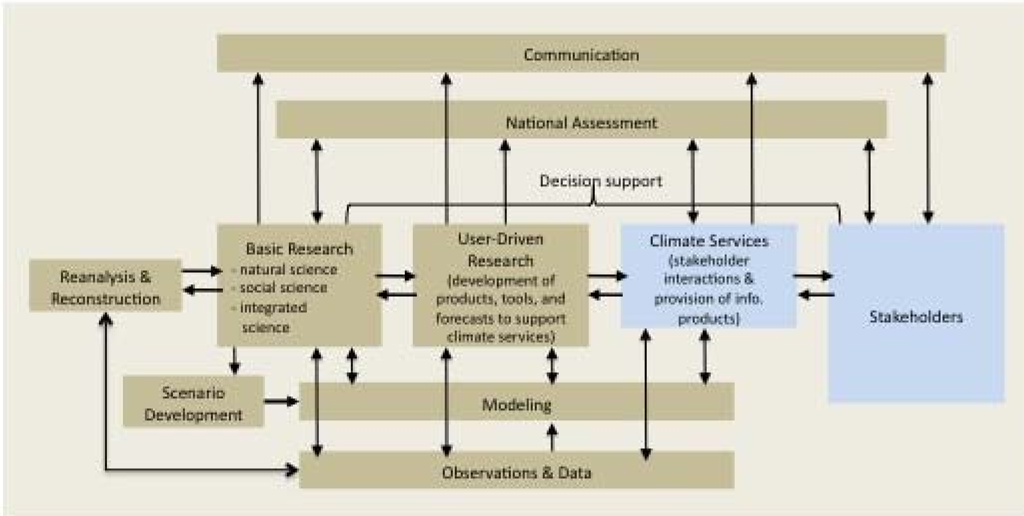

Figure 10. A Restructured Climate Change Research Program[28]

Lack of international cooperation is another issue. The CCSP supports the U.S. contribution to the IPCC but has not actively coordinated U.S. participation in other international programs that address climate-related research. This has resulted in missing opportunities to influence the direction of these programs and find synergies with U.S. programs. Cooperation does occur, but largely through a participation of individual scientists that is not organized to achieve the most benefits. The U.S. research community needs help to work effectively within the international science coordination structures.

The CCSP director has very little funding authority in the current organizational structure. Interagency committees plan future research and cross cutting activities, but essentially all of the funding is controlled and managed by the individual participating agencies. The NRC recommends an increased discretionary budget for the director to provide the CCSP with more ability to influence the climate priorities of participating agencies and implement new research directions that fall outside of or across agency missions.

The importance of an integrated program of Earth system observations raises concerns about the implementing structure. Responsibilities for observations are distributed among the agencies that participate in the CCSP and this program is a logical vehicle for developing a climate observational system. A cross-participant group could identify and prioritize the physical, biological, and social science observations needed, advocate funding, and coordinate with related U.S. and international activities. The participating agencies would have to design the system and determine their respective roles and responsibilities. Another proposal recommends the establishment of an independent Earth Systems Science Agency (ESSA) with a broader function (Schaefer 2008). In this case, a group of senior officials advocate an ESSA whose core mission would be to conduct and sponsor research, development, monitoring, educational and communications activities in earth systems science. Merging the two federal agencies with missions already focused on the major Earth sciences would form this new agency: NOAA and USGS. The ESSA would coordinate its research and development activities with earth science programs at other agencies and maintain a collaborative research bridge to NASA's space-based Earth observing systems and associated research.

A related issue is the lack of a comprehensive strategy for transitioning NASA research satellites into operational NOAA weather and climate satellites (delayed due to budgetary constraints and difference in agency missions). This problem could be overcome by folding those functions into an ESSA (UCAR 2008).

---

[28] Based on Restructuring Federal Climate Research to Meet the Challenges of Climate Change, Fig. 3.2 (NRC 2009a).

8. Key Issues Going Forward

Several key issues emerge from this review of climate change science. We identify the following as critical to continued progress:

- **High-level federal leadership –** Climate change-related activities across the nation, not just the CCSP, need the highest level of attention. This is critical to coordinate activities whose scope touches all aspects of federal government (UCAR 2008). Climate change science would be one facet of a broader portfolio. With respect to that science, national-level leadership is required to facilitate and ensure the necessary cooperation among national and international agencies and programs; promote the optimum balance between extending knowledge and meeting decision makers' needs; adjudicate among competing national government needs for climate science; provide federal agencies with guidance for considering climate issues in management and planning; and maintain federal commitment in the face of changing national priorities. This central role will also be essential if the need arises to refocus climate science research following environmental disasters such as an abrupt climate change. Support from OSTP will be essential for successful leadership of climate science research.
- **An overarching integrated strategy for climate change science –** The NRC has conducted several assessments of different components of climate change science research. One of the most recent provides a functional architecture (see Figure 10) that defines the relationships among these components. An overarching national strategy for climate change science is needed that enables detailing the objectives of each functional element in terms of its contribution to meeting decision makers' needs. Once this is in place, it will be possible to define the interfaces among the elements in terms of roles, responsibilities, and implementing mechanisms. Linkages among observations; experimental; and modeling communities of the physical, biological, and human dimension sciences must be strengthened. As must those with scenario building, mitigation response and adaptation planning activities. An overall strategy will also provide the basis for managing and assessing progress across the enterprise as well as reconciling differing priorities and planning horizons.
- **Preparing decision makers to come to the fore –** Focusing future climate science research to enable informed decision-making is a recurring theme and a laudable goal. But there are many implementation unknowns. Uncertainty about the speed of future climate change and its impacts make it difficult for the majority of decision makers to know what climate-related information they will need, say, ten years from now. How will decision makers' needs be communicated and validated? Mechanisms must be put in place that recognize potential synergies among information needs, as well as identifying when particular needs pull on several different areas of research. An educational program is required to prepare federal, regional, and local decision makers for their responsibilities in influencing future research directions.
- **An observations program capable of underpinning the entire endeavor –** The Decadal Survey recommended that OSTP, in collaboration with the relevant agencies and in consultation with the scientific community, develop and implement a plan for achieving and sustaining global Earth observations (NRC 2007e). The University Corporation for Atmospheric Research (UCAR), the Weather Coalition, the American Meteorological Society, the American Geophysical Union, the Consortium of Universities for the Advancement of Hydrologic Science, the National Association of State University and Land-Grant Colleges, the Consortium for Ocean Leadership, the Alliance for Earth Observations, and the Reinsurance Association of America have endorsed this recommendation. The critical importance of an integrated space-based and ground-based observing system justifies its elevation to a national priority. Moreover, immediate action is required before the essential continuity of climate data records is lost.
- **Elevating international cooperation into a cornerstone of U.S. climate science-related research –** International cooperation is vital to pool scientific expertise and find synergies among programs that both (1) speed resolution of key scientific questions and (2) maximize the employment of limited research capacities and funding. A national strategy that promotes full U.S. support and

participation in international programs such as the WCRP, the International Geosphere-Biosphere Program, and the International Human Dimensions Programme is long overdue. Agencies need additional sources of funding to support these activities and future agency planning activities should be required to explicitly address international cooperative actions.

- **Increased research capacity –** There is a critical need for training climatologists and meteorologists in the ecological and social sciences and future generations of scientists must be trained with the skills to work in multiple domains. Additionally, these scientists must be supported with a research infrastructure that facilitates the exchanges of information across disciplines.

  The intensive computational requirements of climate modeling and the extremely large data sets that result from both modeling and observations are placing increasing stress on scientists' computing and information technology tools. These stresses are rapidly becoming a choke point to further progress. The raw computing hardware appears to be developing in step with climate science requirements, but there is a shortage of software and systems engineers to harness this power in the support of climate science.

- **Increased visibility –** Maintaining a clear picture of the current sets of participants and research programs is essential for supporting the capabilities listed above. This mapping will grow in size and complexity as climate science becomes increasingly interdisciplinary and builds closer connections with increasing numbers of decision-making groups. The CCSP should not be asked to take on the burden of this mapping; instead, an independent group should be established as a U.S. clearinghouse to provide a single point of entry to climate science-related activities and information. The CCSP, representatives from other U.S. climate science-related programs, and representatives from the major international programs should define charter for this clearinghouse.

This paper is one in a series that are examining our understanding of climate change, its impacts, and our options. Any questions about this series or the sources and issues identified in this paper can be addressed to youngb@ida.org.

Acronyms

AOGCM	Atmosphere-Ocean General Circulation Model
AR4	Fourth Assessment Report
CCRI	Climate Change Research Initiative
CCSP	Climate Change Science Program
CDR	Climate Data Records
CO_2	Carbon Dioxide
CORDEX	COordinated Regional climate Downscaling Experiment
DAI	Dangerous Anthropogenic Interference
EPA	Environmental Protection Agency
ESSA	Earth Systems Science Agency
GHG	Greenhouse Gas
GEOSS	Global Earth Observation System of Systems
GtG	Gigatonne Carbon
IDA	Institute for Defense Analyses
IGSM	Integrated Global Systems Model
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute for Climate and Society
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NSF	National Science Foundation
OECD	Organisation for Economic Co-operation and Development
OSTP	Office of Science and Technology Policy
RCM	Regional Climate Model
RISA	Regional Integrated Sciences and Assessments Program
SARP	Sectoral Applications Research Program
SRES	Special Report on Emission Scenarios
TRACS	Transition of Research Applications to Climate Services
UCAR	University Corporation for Atmospheric Research
U.K.	United Kingdom
U.S.	United States
USGS	U.S. Geological Survey
USGCRP	U.S. Global Change Research Program
WCRP	World Climate Research Programme

References

		Section Used
ACIA (2004):	*Arctic Climate Impact Assessment, Supporting Evidence for the Key Findings*. Arctic Climate Impact Assessment. Available at: http://amap.no/acia/.	3
Alcamo (2009):	"Adding Human Dimensions to Earth System Models." Alcamo, J. Paper presented at Climate Change: Global Risks, Challenges and Decisions, In *IOP Conf. Series: Earth and Environmental Science* 6 (2009) 052006.	2
Anthes (2009):	*Testimony by Richard A. Anthes, President of the University Corporation for Atmospheric Research; Co-Chair Committee on Earth Science and Applications from Space (2003–2007), Member, Committee on Earth Sciences, Space Studies Board, National Research Council, The National Academies; and Past President, American Meteorological Society*. Hearing on Satellites and Climate before the Committee on Appropriations, Subcommittee on Commerce, Justice, Science, and Related Agencies, U.S. House of Representatives. March 19, 2009. Available at: http://www.appropriations.house.gov/Witness_testimony/CJS/Dr._Richard_Anthes_3_19_09.pdf.	6
ASAC-BERAC (2008):	*Report on Computational and Informational Technology Rate. Limiters to the Advancement of Climate Change Science*. J.J. Hack & E. Bierly (Eds.), Advanced Scientific Computing Advisory Committee and Biological and Environmental Advisory Committee. Department of Energy. March 17, 2008. Available at: http://www.er.doe.gov/ascr/ASCAC/ Reports/JointASCACBERACReport.pdf.	2
Bows (2009):	*Making a Climate Commitment: Analysis of the first Report (2008) of the UK Committee on Climate Change.* Bows, A., D. Calverley, J.Broderick, and K. Anderson. A research report by Tyndall Centre, University of Manchester. March 2009. Available at: http://www.tyndall.ac.uk/publications/Tyndall_Review_of_CCC_Report.pdf.	3
Bryden et al. (2005):	"Slowing of the Atlantic meridional overturning circulation at 25°N." Bryden, H.L., H.R. Longworth, and S.A. Cunningham. 2005. *Nature*, 438: 655–657. Available at: http://www. nature.com/nature/journal/v438n7068/abs/nature04385.html.	3
Carlson et al. (2008):	"Rapid Early Holocene Deglaciation of the Laurentide ice sheet." Carlson, A.E., A.N. Le Grande, D.W. Oppo, R.E. Came, G.A. Schmidt, F.S. Anslow, J.M. Licciardi & E.A. Obbink. *Nature Geoscience*, 1: 620–624 (2008). Available at: http://www.nature.com/ngeo/journal/v1/n9/abs/ngeo 285.html.	3
CCSP (2009a):	*Our Changing Planet, The U.S. Climate Change Science Program for Fiscal Year 2009.* A Report by the Climate Change Science Program and the Subcommittee on Global Change Research, A Supplement to the President's Budget for Fiscal Year 2009. July 2008. Washington, DC: Climate Change Science Program Office. Available at: http://www.usgcrp.gov/usgcrp/Library/ocp2009/.	2, 4
CCSP (2009b):	*Best practice approaches for characterizing, communicating, and incorporating scientific uncertainty in decision making*. Final Report of Synthesis and Assessment Product 5.2. Washington, DC: Climate Change Science Program Office. Available at: http://www.climatescience.gov/Library/sap/sap5-2/default.php.	6
CCSP (2008a):	*Climate Models: An Assessment of Strengths and Limitations*. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research [Bader D.C., C. Covey, W.J. Gutowski Jr., I.M. Held, K.E. Kunkel, R.L. Miller, R.T. Tokmakian and M.H. Zhang (Authors)]. Department of Energy, Office of Biological and Environmental Research, Washington, D.C. Available at: http://www.climatescience.gov/Library/sap/sap3-1/final-report/sap3-1-final-all.pdf.	2
CCSP (2008b):	*Preliminary review of adaptation options for climate-sensitive ecosystems and resources.* A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Julius, S.H., J.M. West (eds.), J.S. Baron, B. Griffith, L.A. Joyce, P. Kareiva, B.D. Keller, M.A. Palmer, C.H. Peterson, and J.M. Scott (Authors)]. U.S. Environmental Protection Agency, Washington, DC. Available at: http://downloads.climatescience.gov/sap/sap4-4/sap4-4-final-report-all.pdf.	2

CCSP (2008c):	*Climate Projections Based on Emissions Scenarios for Long-Lived and Short-Lived Radiatively Active Gases and Aerosols*. Final Report, Synthesis and Assessment Product 3.2. Washington, DC: Climate Change Science Program Office. Available at: http://www.climatescience.gov/Library/sap/sap3-2/default.php.	2
CCSP (2008d):	*Reanalysis of Historical Climate Data for Key Atmospheric Features: Implications for Attribution of Causes of Observed Change*. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research [Randall Dole, Martin Hoerling, and Siegfried Schubert (eds.)]. National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC. Available at: http://www.climatescience.gov/Library/sap/sap1-3/final-report/.	2
CCSP (2008e):	*Abrupt Climate Change*. Final Report, Synthesis and Assessment Product 3.4. Washington, DC: Climate Change Science Program Office. Available at: http://www.climatescience.gov/Library/sap/sap3-4/final-report/.	3
CCSP (2008f):	*Revised Research Plan for the U.S. Climate Change Science Program*. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research. May 2008. Washington, DC: Climate Change Science Program Office. Available at: http://www.climatescience.gov/Library/stratplan2008.	4
CCSP (2008g):	*Decision support experiments and evaluations using seasonal to interannual forecasts and observational data*. Final Report, Synthesis and Assessment Product 5.3. Washington, DC: Climate Change Science Program Office. Available at: http://www.climatescience.gov/Library/sap/sap5-3/final-report/.	5
CCSP (2008h):	*Uses and limitations of observations, data, forecasts, and other projections in decision support for selected sectors and regions*. Final Report, Synthesis and Assessment Product 5.1. Washington, DC: Climate Change Science Program Office. Available at: http://www.climate science.gov/Library/sap/sap5-1/final-report/.	5
CCSP (2008i):	*Observations for Climate for 2008: National Activities with Respect to the Global Climate Observing System (GCOS) Implementation Plan*. Prepared for Submission to the United Nations Framework Convention on Climate Change (UNFCCC). Compiled by the Observations Working Group of the U.S. Climate Change Science Program (CCSP) On Behalf of the United States Government. September 2008. Available at: http://www.climatescience.gov/Library/UNFCCC-report.htm.	6
CCSP (2007a):	*Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations (Part A).* Synthesis and Assessment Product 2.1a. Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Washington, DC: Department of Energy, Office of Biological & Environmental Research. Available at: http://www.climate science.gov/Library/sap/sap2-1/default.php.	2
CCSP (2007b):	*Global-Change Scenarios, Their Development and Use.* Synthesis and Assessment. Product 2.1b. Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Washington, DC: Department of Energy, Office of Biological & Environmental Research. Available at: http://www.climatescience.gov/Library/sap/sap21/default.php.	2
Chapin et al. (2005):	"Role of Land-Surface Changes in Arctic Summer Warming." Chapin, F.S. III, M. Sturm, M.C. Serreze, J.P. McFadden, J. R. Key, A. H. Lloyd, A. D. McGuire, T. S. Rupp, A. H. Lynch, J. P. Schimel, J. Beringer, W. L. Chapman, H. E. Epstein, E. S. Euskirchen, L. D. Hinzman, G. Jia, C.-L. Ping, K. D. Tape, C. D. C. Thompson, D. A. Walker, and J. M. Welker. 2005. "*Science*, 310(5748): 657–660. Available at: http://www.sciencemag.org/cgi/content/abstract/1117368v1.	3
Christoffersen & Hambrey (2006):	"Is the Greenland Ice Sheet in a State of Collapse?" Christoffersen, P. and M.J. Hambrey. 2006. *Geology Today*, 22(3), May–June. Available at: http://www3.interscience.wiley.com/journal/118621650/abstract?CRETRY=1&SRETRY=0.	3
Climate Congress (2009):	*Key Messages from the Congress. Climate Change: Global Risks, Challenges & Decisions, Copenhagen 2009*, 10–12 March. Available at: http://climatecongress.ku.dk/newsroom/congress_keymessages/.	1, 3
Dietz & Stern (1998):	"Sciences, values, and biodiversity." Dietz, T. & P.C. Stern. *BioSciences*, 48: 441–444.	5

DoE (2008a):	*Identifying Outstanding Grand Challenges in Climate Change Research: Guiding DoE's Strategic Planning*. Report on the DOE/BERAC Workshop, September 3, 2008. Available at: http://www.sc.doe.gov/ober/berac/Grand_Challenges_Report.pdf.	2
DoE (2008b):	*Report of the workshop on Exploring Science Needs for the Next Generation of Climate Change and Elevated-CO2 Experiments in Terrestrial Ecosystems*. Authors: Hanson, P.E., A. Classen, L. Kueppers, Y. Luo, N.G. McDowell, J. Morris, A. Rogers, P. Thornton, R. Ceulemans, J. Dukes, M. Goulden, R. Jackson, A. Knapp, M. Kirschbaum, K. Lewin, M. MacCracken, J. Melillo, T. Ringler, and Workshop Participants. Workshop held April 14-18 2008, Arlington, Virginia. Oak Ridge National Laboratory, Department of Energy. Available at: http://www.sc.doe.gov/ober/CCRD/Experiment%20Workshop%20Report%2023Feb2009.pdf.	2
Eisenman (2099):	"Is Arctic sea ice approaching a tipping point?" Eisenman, I. and J. S. Wettlaufer. Paper presented at the 10th Conference on Polar Meteorology and Oceanography, May 18–21 2009, Madison, WI.	3
EPA (2009):	*2009 U.S. Greenhouse Gas Inventory Report*. Inventory of U.S. greenhouse Gas Emissions and Sinks: 1990-2007 (April 2009). Washington, DC: Environmental Protection Agency. Available at: http://insideepa.com/secure/data_extra/dir_09/epa 2009_0648.pdf.	3
EPA (2006):	*Global Mitigation of Non-CO_2 Greenhouse Gases*. (EPA Report 430-R-06-005). June 2006. Washington, DC: Environmental Protection Agency. Available at: http://www.epa.gov/climatechange/economics/downloads/GlobalMitigationFullReport.pdf.	3
Gallagher (2009):	*Monitoring, Measurement and Verification of Greenhouse Gas Emissions II: The Role of Federal and Academic Research and Monitoring Programs.* Testimony of Patrick D. Gallagher, Ph.D. National Institute of Standards and Technology, U.S. Department of Commerce, Before the Committee on Science and Technology, U.S. House of Representatives. Available at: http://science.house.gov/publications/Testimony.aspx?TID=15050.	6
GAO (2009a):	*Climate Change, Observations on Federal Efforts to Adapt to a Changing Climate*. Testimony before the Subcommittee on Energy and Environment, Committee on Energy and Commerce, House of Representatives. Statement of John Stephenson, Director of Natural Resource and Environment. GAO-09-534T. Washington, DC: U.S. Government Accountability Office. Available at: http://www.gao.gov/ products/GAO-09-534T.	4
GAO (2009b):	Geostationary Operational Environmental Satellites: Acquisition is Under Way, but Improvements Needed in Management and Contractor Oversight. GAO-09-323, April 2009. Washington, DC: US Government Accountability Office. Available at: http://www.gao.gov/new.items/d09323.pdf.	
Häkkinen & Rhines. (2004):	"Decline of Subpolar North Atlantic Circulation during the 1990s." Häkkinen, S. and P.B. Rhines. April 2004. *Science*, 304: 555–559. Available at: http://www.sciencemag.org/cgi/content/abstract/1094917.	3
Hansen (2007):	"Dangerous Human-Made Interference with Climate: a GISS modelE Study." Hansen, J., M. Sato, R. Ruedy, P. Kharecha, A. Lacis, R. Miller, L. Nazarenko, K. Lo, G.A. Schnidt, G. Russell, I. Aleinov, S. Bauer, E. Baum, B. Cairns, V. Canuto, M. Chandler, Y. Cheng, A. Coehn, A. Del Genio, G. Faluvegi, E. Fleming, A. Friend, T. Hall, C. Jackman, J. Jonas, M. Kelley, N.Y. Kiang, D. Koch, G. Labow, J. Lerner, S. Menon, T. Novako, V. Oinas, Ja. Perlwitz, Ju. Perlwitz, D. Rind, A. Romanou, R. Schmunk, D. Shindell, P. Stone, S. Sun, D. Streets, N. Tausnev, D. Thresher, N. Unger, M. Yao, and S. Zhang. 2007. *Atmospheric Chemistry and Physics*, 7: 2287–2312. Available at: http://www.atmos-chemphys.org/7/2287/2007/acp-7-2287-2007.pdf.	3
Hare (2008):	*Ice Sheets and Sea Level, New Insights since IPCC 2007*. Hare, W. Earth Systems Analysis, Potsdam Institute for Climate Impact Research. Available at: http://copportal1.man.poznan.pl/Doc.ashx?Id=51&Mime=application/pdf&Presentation=True.	3
Heimann & Reichstein (2008):	"Terrestrial Ecosystem Carbon Dynamics and Climate Feedbacks." Heinmann, M. and M. Reichstein. *Nature*, 451, 289–292. Available at: http://www.nature.com/nature/journal/v451/n7176/full/nature06591.html.	2

Hurrell (2008):	"Decadal Climate Prediction: Challenges and Opportunities." Hurrell, J. *Journal of Physics: Conference Series*, *125* (2008) 012018. Available at: http://www.iop.org/EJ/article/17426596/125/1/012018/jpconf8125_012018.pdf?requestid=e4cc8cfc-81ee-4158-97ff-c265788047ab.	2
IEA (2008):	*World Energy Outlook 2008*. Paris, France: International Energy Agency. Available at: http:// www.iea.org/weo/2008.asp.	3
IPCC (2007):	*Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the IPCC. Available at: http://www.ipcc.ch/ipcc reports/ar4wg1.htm.	
IPCC (2001):	*Climate Change 2001: Synthesis Report.* Intergovernmental Panel on Climate Change. Available at: http://www.ipcc.ch/ipccreports/tar/vol4/english/index.htm.	3
IPCC (2000):	*IPCC Special Report on Emission Scenarios*. Nakicenovic, N. and R. Swart (Eds.) 2000. Available at: http://www.grida.no/publications/other/ipcc%5Fsr/?src=/climate/ipcc/emission/.	2
Johnson (2008):	Johnson, T. *G8's Gradual Move toward Post-Kyoto Climate Change Policy*. Washington, DC: Council on Foreign Relations. January 25, 2008. Available at: http://www.cfr.org/publication/13640/.	3
Karl (2009):	*Written Testimony of Thomas R. Karl, L.H.D. National Oceanic and Atmospheric Administration, U.S. Department of Commerce*. Hearing on Satellites and Climate before the Committee on Appropriations, Subcommittee on Commerce, Justice, Science, and Related Agencies, U.S. House of Representatives. March 18, 2009. Available at: http://www.legislative.noaa.gov/Testimony/Karl032509.pdf.	2
Kuhlbrodt et al. (2007):	Kuhlbrodt, T., S. Rahmstorf, K. Zickfeld, F. Vikebo, S. Sundby, M. Hofmann, P.M. Link, A. Bondeau, W. Cramer, and C. Jaeger. 2007. "An Integrated Assessment of Changes in the Thermohaline Circulation." *Climatic Change*. Submitted. Available at: http://climate.uvic.ca/people/zickfeld/integration_synthesis.pdf.	3
Lenton et al. (2008):	Lenton, T.M., H. Held, E. Kriegler, J.W. Hall, W. Lucht, S. Rahmstorf, and H.J. Schellnhuber. February 2008. "Tipping elements in the Earth's climate system." *PNAS*, 105(6): 786–1793. Available at: http://www.pnas.org/content/105/6/1786.full.pdf.	3
Lucas et al. (2007):	Lucas, C., K. Hennessy, G. Mills, and J. Bathols. September 2007. *Bushfire Weather in Southeast Australia: Recent Trends and Projected Climate Change Impacts*. Consultancy Report prepared for the Climate Institute of Australia. Available at: http://www.bushfirecrc.com/research/downloads/climate-institute-report-september 2007.pdf.	3
Mann (2009):	Mann, M.E. "Defining dangerous anthropogenic interference." *PNAS*, March 17, 2009, 106(11): 4065–4066. Available at: http://www.pnas.org/content/early/2009/03/09/0901303106.full.pdf.	3
Matthews et al. (2008):	Matthews, H. D., and K. Caldeira (2008), Stabilizing climate requires near-zero emissions, *Geophys. Res. Lett.*, 35, L04705. Available at: http://www.agu.org/pubs/crossref/2008/2007GL032388.shtml.	3
Mearns (2009):	Mearns, L. "The North American Regional Climate Change Assessment Program (NARCCAP): Overview of Phase II Results." Paper presented at Climate Change: Global Risks, Challenges and Decisions, In *IOP Conf. Series: Earth and Environmental Science* 6 (2009) 05200.	2
Meinshausen (2005):	Meinshausen, M. "On the Risk of Overshooting 2°C." Paper presented at the 2632nd Council Meeting Environment, Luxembourg. Available at: http://www.stabilisation2005.com/14_Malte_Meinshausen.pdf.	3
Miles (2006):	E. L. Miles, A. K. Snover, L. C. Whitely Binder, E. S. Sarachik, P. W. Mote, and N. Mantua. "Inaugural Article: An approach to designing a national climate service." *PNAS*, 2006 103: 19616–19623. Available at: http://www.pnas.org/content/103/52/19616.full.	4

Murawski (2008):	Murawski, S. *Integrated Ecosystem Assessments for the South Atlantic: the time has come*. 6, 2008. NOAA in the Carolinas. Available at: http://www.carolinas.noaa.gov/Presentations/Murawski_IEAs.pdf.	2
Murphy et al. (2007):	Murphy, J.M., B.B.B. Booth, M. Collins, G.R. Harris, D.M.H. Sexton, and M.J Webb. "A Methodology for Probabilistic Predictions of Regional Climate Change from perturbed Physics Ensembles." *Phil. Trans. R. Soc. A*, 2007, 365, 1993–2008. Available at: http://rsta.royalsocietypublishing.org/content/365/1857/1993.abstract.	2
Naish (2009):	Naish, T. & R. Powell. "Extracting ice sheet's past reveals what a warmer future might hold." *Nature*, 458, 258 (19 March 2009). Available at: http://www.nature.com/nature/journal/v458/n7236/full/7236258a.html	3
NASA (2006):	*Greenland Ice Sheet on a Downward Slide*. Goddard Space Flight Center. Maryland: NASA. Available at: http://www.nasa.gov/centers/goddard/news/topstory/2006/greenland_slide.html.	3
New Scientist (2005):	"Climate Warming as Siberia Melts." August 11. *NewScientist.com*. Available at: http://www.newscientist.com/article/mg18725124.500.	3
NOAA (2009):	*Options for Developing a National Climate Service*. A report from the Climate Working Group of the NOAA Science Advisory Board. February 26, 2009. Available at: http://www.sab.noaa.gov/Meetings/2009/NCS%20_Report_2-26-09_FINALtoSAB.pdf.	4
NOAA (2008):	*Carbon Dioxide, Methane Rise Sharply in 2007*. National Oceanic and Atmospheric Administration, Department of Commerce. (April 23, 2008) Available at: http://www.noaanews.noaa.gov/stories2008/20080423_methane.html.	3
NRC (2009a):	*Restructuring Federal Climate Research to Meet the Challenges of Climate Change*. Committee on Strategic Advice on the U.S. Climate Change Science Program. Washington, DC: The National Academies Press. Available at: http://www.nap.edu/catalog/12595.html.	4, 6, 7
NRC (2009b):	*Informing Decisions in a Changing Climate*. Panel on Strategies and Methods for Climate-Related Decision Support, Committee on the Human Dimensions of Climate Change, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press. Available at: http://www.nap.edu/catalog.php?record_id=12626.	5
NRC (2008):	*Observing Weather and Climate from the Ground Up: A Nationwide Network of Networks*, Committee on Developing Mesoscale Meteorological Observational Capabilities to Meet Multiple Needs. Washington, DC: The National Academies Press. Available at: http://dels.nas.edu/basc/reportDetail.php?link_id=5542.	6
NRC (2007a):	*Understanding Multiple Environmental Stresses: Report of a Workshop*. Committee on Earth-Atmosphere Interactions: Understanding and Responding to Multiple Environmental Stresses. Washington, DC: The National Academies Press. Available at: http://www.nap.edu/catalog/11748.html.	2
NRC (2007b):	*Evaluating Progress of the U.S. Climate Change Science Program: Methods and Preliminary Results*. Committee on Strategic Advice on the U.S. Climate Change Science Program. Washington, DC: The National Academies Press. Available at: http://www.nap.edu/catalog/11934.html.	2, 6, 7
NRC (2007c):	Research and Networks for Decision Support in the NOAA Sectoral Applications Research. *Panel on Design Issues for the NOAA Sectoral Applications Research Program.* Helen M. Ingram and Paul C. Stern, Editors. Available at: http://books.nap.edu/catalog.php?record_ id=12015.	5
NRC (2007d):	*Analysis of Global Change Assessments: Lessons Learned*. Committee on Analysis of National Research Council. Washington, DC: The National Academies Press. Available at: http://www.nap.edu/catalog/11868.html.	5
NRC (2007e):	*Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*. Committee on Earth Science and Applications from Space: A Community Assessment and Strategy for the Future. Washington, DC: National Research Council. Available at: http://www.nap.edu/catalog/11820.html.	6

NRC (2006):	*Surface Temperature Reconstructions for the Last 2,000 Years*. Committee on Surface temperature Reconstruction for the Last 2,000 Years. Washington, DC: The National Academies Press. Available at: http://www.nap.edu/catalog/11676.html.	2
NRC (2005):	*Decision making for the Environment*. Garry D. Brewer, G. and P. C. Stern, *Editors*. Panel on Social and Behavioral Science Research Priorities for Environmental Decision Making, Committee on the Human Dimensions of Global Change, National Research Council. Available at: http://www.nap.edu/catalog.php?record_id=11186.	5
NRC (2002):	*Abrupt Climate Change: Inevitable Surprises*. Committee on Abrupt Climate Change, Washington, DC: National Research Council. Available at: http://www.nap.edu/catalog.php?record_id=10136.	2
NRC (2001):	*A Climate Services Vision, first steps toward the future*. Board on Atmospheric Sciences and Climate, Division on Earth and Life Studies. Washington, DC: National Research Council. Available at: http://www.nap.edu/catalog/10198.html.	4
NSF (2007):	“Glaciers and Ice Caps to Dominate Sea-level Rise through 21st Century.” *NSF Press Release*, No. 07-083, July 19. Available at: http://www.nsf.gov/news/news_summ.jsp?cntn_id=109759.	3
NSIDC (2009):	“Ice Bridge Supporting Wilkins Ice Shelf Collapses.” NSIDC, 8 April 2009 Media Advisory. Available at: http://nsidc.org/news/press/20090408_Wilkins.html.	3
NSIDC (2007):	*Arctic Sea Ice News Fall 2007*. National Snow and Ice Data Center. Available at: http://nsidc.org/news/press/2007_seaiceminimum/20070810_ index.html.	3
Oxfam (2007):	*Climate Alarm: Disasters increase as climate change bites*. Oxfam Briefing Paper 108, November 2007. Available at: http://www.oxfam.org.uk/resources/policy/climate_change/bp108_weather_alert.	3
Parry et al. (2008):	“Squaring Up to Reality.” Parry M., J. Palutikof, C. Hanson, & J. Lowe. *Nature Reports*, Vol. 2, June 2008. Available at: http://www.nature.com/climate/2008/0806/full/climate.2008.50.html.	3
Pew (2009):	*Adaptation Planning: What U.S. States and Localities are Going*. Prepared for the Pew Center on Global Climate Change, November 2007, updated January 2009. Available at: http://www.pewclimate.org/workingpapers/adaptation.	4
Princiotta (2008):	*Global Climate Change and the Mitigation Challenge*. Princiotta, F. Office of Research and Development, U.S. Environmental Protection Agency. Available at: http://www.apcas.qc.ca/2008octPriciottaword.pdf.	3
Rahmstorf (2009):	*Sea Level Rise*. Rahmstorf, S. Potsdam Institute for Climate Impact Research. Available at: http://climatecongress.ku.dk/speakers/stefanrahmstorf-plenaryspeaker 10march2009.pdf/.	3
Rahmstorf (2007):	“Recent Climate Observations Compared to Projections.” Rahmstorf, S., A. Cazenave, J.A. Church, J.E. Hansen, R.F. Keeling, D.E. Parker, and R.C.J. Somerville. May 2007. *Science*, 316(5825): 709. Available at: http://www.sciencemag.org/cgi/content/full/316/5825/709.	3
Ramanthan & Feng (2008):	“On avoiding dangerous anthropogenic interference with the climate system: Formidable challenges ahead.” Ramanathan, V. & Y. Feng. Published online September 17, 2008. Available at: http://www.pnas.org/content/early/2008/09/16/08033838105.abstract	3
Rignot et al. (2008):	“Recent Antarctic ice mass loss from radar interferometry and regional climate modeling.” Rignot, E., J.L. Bamber, Michiel R. van den Broeke, C. Davis, Y. Li, W.J. van de Berg, & E. van Meijgaard. *Nature Science* (2008). Available at: http://www.nature.com/ngeo/journal/v1/n2/abs/ngeo102.html.	3
Rignot & Kanagaratnam (2006):	“Changes in the Velocity of the Greenland Ice Sheet.” Rignot, E. and P. Kanagaratnam. 2006. *Science*, 331(5763): 986–990. Available at: http://www.sciencemag.org/cgi/ content/abstract/311/5763/986.	3

Schaefer et al. (2008):	"An Earth Systems Science Agency." Schaefer, M., D.J. Baker, J.H. Gibbons, C.G. Groat, D. Kennedy, C.F. Kennel, & D. Rejeski. *Science, Policy Forum*, 4 July 2008: 321(5885): 44–45. Available at: http://www.sciencemag.org/cgi/content/summary/321/5885/44.	7
Scheffer et al. (2006):	"Positive feedback between global warming and atmospheric CO2 concentration inferred from past climate change." Scheffer, M., V. Brovkin, and P. Cox. May 2006. *Geophysical Research Letters*, 33, 10. Available at: http://www.pikpotsdam.de/~victor/recent/scheffer_etal_T_CO2_GRL_in_press.pdf.	
Schlosser et al. (2007):	*A Global Land System Framework for Integrated Climate-Change Assessments*. Schlosser, C.A., D. Kicklighter and A. Sokolov (May 2007). Joint Program Report Series, 2007, Report 147. Available at: http://globalchange.mit.edu/pubs/abstract.php?publication_id=720.	2
Serreze & Stroeve (2008):	"Standing on the Brink." Serreze, M.C. and J.C. Stroeve. *Nature Reports*, Vol. 2, November 1008, Commentary. Available at: http://www.nature.com/climate/2008/0811/full/climate.2008.108.html.	3
Shephard et al. (2007):	"Recent Sea-Level Contributions of the Antarctic and Greenland Ice Sheets." Shephard, A. and D. Wingham. March 2007. *Science*, 315: 1529–1532. Available at: http://www.sciencemag.org/cgi/content/abstract/315/5818/1529,	3
Smedsrud et al. (2008):	"Recent and future changes of the Arctic sea-ice cover." Smedsrud, L.H., A. Sorteberg, and K. Kloster. *Geophysical Research Letters*, 35, L20503, 2008. Available at: ftp://ftp.nersc.no/Press/Smedsrud08.pdf.	3
Smith (2009):	"Assessing dangerous climate change through an update of the Intergovernmental Panel on Climate Change (IPCC) "reasons for concern." Smith, J.B., S.H. Schneider, M. Oppenheimer, G.W. Yohe, W. Hare, M.D. Mastrandrea, A. Patwardhan, I. Burton, J. Corfee-Morlot, C.H.D. Magadza, H.-M. Füssel, A.B. Pittock, A. Rahman, A. Suarez, and J.-P. van Ypersele. Published online before print February 26, 2009. Available at: http://www.pnas.org/content/early/2009/02/25/0812355106.	3
Solomon et al. (2008):	"Irreversible climate change due to carbon dioxide emissions." Solomon, S., G.-K. Plattner, R. Knutti, and P. Friedlingstein. *PNAS*, February 10, 2009 106(6): 1704–1709. Available at: http://www.pnas.org/content/106/6/1704.full.	3
Stainforth & Smith (2009):	"Quantifying Uncertainty, Interpreting Ensembles and Combining Models with Process Understanding." Stainforth, D. and L. Smith.	2
Stern & Wilbanks (2009):	"Fundamental Research Priorities to Improve the Understanding of the Human Dimensions of Climate Change." Stern, P.C. and T.J. Wilbanks. "Appendix D in *Restructuring Federal Climate Research to Meet the Challenges of Climate Change*. Committee on Strategic Advice on the U.S. Climate Change Science Program. Washington, DC: The National Academies Press. Available at: http://www.nap.edu/catalog/12595.html.	2
Stroeve et al. (2007):	"Arctic Sea Ice Decline: Faster than Forecast?" Stroeve, J., M. Holland, M. Serreze, T. Scambos, and W. Meier. 2007. *Geophys. Res. Lett.,* 34, L09501. Available at: http://www.agu.org/pubs/crossref/2007/2007GL029703.shtml.	3
Tirpak (2005):	*Avoiding Dangerous Climate Change*. International Symposium on the Stabilisation of greenhouse gas concentrations, 1-3 February 2005. Hadley Centre, Met Office, Exeter, U.K. Available at: http://www.defra.gov.uk/environment/climatechange/research/dangerous-cc/pdf/avoid-dangercc-execsumm.pdf.	3
Tol (2005):	*Europe's Long Term Climate Target: A Critical Evaluation.* Tol, R.S.J., FNU-92, Hamburg University and Centre for Marine and Atmospheric Science, Hamburg. Available at: http://ideas.repec.org/p/sgc/wpaper/92.html.	3
Trenberth (2008):	"Progress and Prospects for Reanalysis for Weather and Climate." Trenberth, K.E. *EOS*, 89: 234–235. Available at: http://www.wmo.ch/pages/prog/wcrp/documents/Trenberth_EOS_Reanalysis_0608.pdf.	

Truffer & Fahnestock (2007):	"Climate Change: Rethinking Ice Sheet Time Scales." Truffer, M. and M. Fahnestock**.** *Science*, 16 March 2007: 315(5818): 1508–1510. Available at: http://www.sciencemag.org/cgi/content/short/315/5818/1508.	3
Tyrrell et al. (2007):	"The long-term legacy of fossil fuels." Tyrrell T., J.G. Shepherd, S. Castle (2007) *Tellus B*, 59: 664-672. Available at: http://www3.interscience.wiley.com/journal/118533123/abstract?CRETRY=1&SRETRY=0.	3
UCAR (2008):	*Advice to the New Administration and Congress: Actions to make our National resilient to severe weather and climate change*. November 20, 2008. University Corporation for Atmospheric Research, American Meteorological Society, American Geophysical Union, Alliance for Earth Observations and others. Available at: http://www.ucar.edu/td/transition.pdf.	2, 6, 7
UN (1992):	*Article 2 of the United Nations Framework Convention on Climate Change*. United Nations. Available at: http://unfccc.int/essential_background/convention/items/2627.php.	3
UNEP (2008):	*Methane from the Arctic: Global warming wildcard*. In *UNEP Year Book*. Nairobi, Kenya: United Nations Environment Programme. Available at: http://www.unep.org/geo/yearbook/yb2008/report/Emerging.pdf.	3
University of Washington (2009):	University of Washington (2009): *Ice-Free Arctic Ocean Possible in 30, Not 90, Years*. April 6, 2009. University of Washington. Available at: http://www.sciencedaily.com/releases/2009/04/090402143752.htm.	3
USARC (2003):	*Climate Change, Permafrost, and Impacts on Civil Infrastructure*. U.S. Arctic Research Commission, Permafrost Task Force Report. December 2003. Available at: http://www.arctic.gov/files/PermafrostForWeb.pdf.	3
USGS (2007):	*Facing Tomorrow's Challenges–U.S. Geological Survey Science in the Decade 2007 – 2017*. USGS Circular 1309. Department of the Interior. Available at: http://pubs.usgs.gov/circ/2007/1309/.	2
van Vuuren (2008):	"Temperature increase of 21st century mitigation scenarios." Van Vuuren, D. P., M. Meinshausen, G.-K. Plattner, F. Joos, K. M. Strassmann, S. J. Smith, T. M. L. Wigley, S. C. B. Raper, K. Riahi, F. de la Chesnaye, M. G. J. den Elzen, J. Fujino, K. Jiang, N. Nakicenovic, S. Paltsev, and J. M. Reilly. *PNAS*, October 7, 2008 105(40): 15258-15262. Available at: http://www.pnas.org/content/105/40/15258.full.	3
Vimont & Solomon (2008):	*A Prospectus for a US-CLIVAR Working Group On Decadal Predictability*. Vimont, D.J. and A. Solomon. 2008. Available at: http://www.usclivar.org/summit2008/PPAI/DPWG_prospectus_revised_071108.pdf.	2
Wang & Overland (2009):	"A sea ice free summer Arctic within 30 years?" *Geophysical Res. Letters*, 36, L07502. Available at: http://www.sciencedaily.com/releases/2009/04/090402143752.htm.	3
WCRP (2009a):	*Workshop Report, World Modelling Summit for Climate Prediction*. Workshop held May 6-9, 2008 at the European Centre for Medium-Range Weather Forecasts, Reading, U.K. WCRP No. 131, WMO/TD No. 1468. Available at: http://www.wmo.ch/pages/prog/wcrp/documents/WCRP_WorldModellingSummit_Jan2009.pdf.	2
WCRP (2009b):	*Evaluating and Improving Regional Climate Projections – Workshop Report from Dr. Filippo Giorgi.* WCRP News. 20.02.2009. Available at: http://www.wmo.ch/pages/prog/wcrp/documents/WCRPnews_20090226.pdf.	2
WCRP (2008a):	*Future Climate Change Research and Observations: GCOS, WCRP and IGBP Learning from the IPCC Fourth Assessment Report*. Workshop and Survey Report, GCOS-117, WCRP-127, IGBP Report No. 58 (WMO/TD No. 1418). January 2008. World Climate Research Programme. Available at: http://wcrp.ipsl.jussieu.fr/Documents/ACC/Sydney2007/SydneyWorkshopRep_FINAL.pdf.	2
WCRP (2008b):	*WCRP Position Paper on Seasonal Prediction*. Report from the First WCRP Seasonal Prediction Workshop (Barcelona, Spain, 4-7 June 2007). February 2008. WCRP Informal Report No. 3/2008. ICPO Publication No. 127. Available at: http://www.clivar.org/organization/wgsip/references/WCRP_SeasonalPrediction PositionPaper_Feb2008.pdf.	2

WCRP (2008c):	*Third WCRP International Conference on Reanalysis, Conference Statement*. World Climate Research Programme. Available at: http://www.wmo.ch/pages/prog/wcrp/documents/wcrp3rac_statement.pdf.	2
WCRP (2007):	*Cross-Cutting Topic: Decadal Prediction*. Joint Scientific Committee, 28th Session, Zanzibar, Tanzania, 26–30 March 2007. JSC-XXVIII/Doc 2.4, 13.11.2007. World Climate Research Programme. Available at: http://www.clivar.org/organization/ssg/ssg15/docs/Doc%202.4%20DECADAL%20PREDICTION%2013.02.pdf.	
Weaver et al. (2007):	"Long term climate implications of 2050 emission reduction targets." Weaver, A. J., K. Zickfeld, A. Montenegro, and M. Eby (2007), *Geophys. Res. Lett.*, *34*, L19703. Available at: http://www.agu.org/pubs/crossref/2007/2007GL0 31018.shtml.	3
Wentz et al. (2007):	Wentz, F.J., L. Ricciardulli, K. Hilburn, and C. Mears. July 2007. "How much more rain will global warming bring?" *Science*, 317(5835): 223–235. Available at: http://www.sciencemag.org/cgi/content/abstract/1140746.	3
Woodward (2007):	"Curbing Climate Change, Is the World Doing Enough?" Woodward, C. 2007. *CQ Global Researcher*, 1(2): 27–50. February 2007.	3
Zwally et al. (2005):	"Mass Changes of the Greenland and Antarctic Ice Sheets and Shelves and Contributions to Sea-Level Rise 1992–2002." Zwally, H.J., M.B. Giovinetto, J. Li, H.G. Cornejo, M.A. Beckley, A.C. Brenner, J.L. Saba, and D. Yi. 2005. *Journal of Glaciology*, 51(175): 509–527. Available at: http://adsabs.harvard.edu/abs/2005 JGlac..51..509Z.	3

Appendix A: Chronology of Events Significant for Climate Change Science

This chronology provides a timeline for major assessments, reports, conferences, and congressional hearings on the topic of climate change science. It lists all of the CCSP synthesis and assessment products, IPCC assessments, and those NRC reports that discuss climate change science. We have attempted to identify all of the relevant Congressional hearings and proposed legislation for 2009, but entries for 2008 and 2007 are restricted to particularly important hearings, although all relevant legislative proposals are captured. Coverage of important other kinds of events becomes similarly less comprehensive for each previous year.

2014		Activity / Event	Type
2014		IPCC expected to release its Fifth Assessment Report (AR5).	IPCC

2009		Activity / Event	Type
Sep	9/31/09 – 10/4/09	World Climate Conference-3 scheduled for Aug 31 – Sep 4, Geneva. The overarching theme: Climate prediction for decision-making: focusing on seasonal to interannual time-scales.	Conference
Sep	9/28/09 – 9/30/09	International Climate Conference 4 Degrees and Beyond, Implications of a global climate change of 4+ degrees for people, ecosystems, and the earth-system, Oxford, U.K. Sponsored by the Tyndall Center and University of Oxford.	Conference
Jun	6/17/09	Select Committee on Energy Independence and Global Warming hearing on "Global Warming's Impact on Agriculture and Forestry." Testimony from Jerry Hatfield, Heather Cooley, Tom Troxel, Dr. Johannes Lehmann, and Ford B. West.	Hearing
Jun	6/16/09	USGCRP release Global Climate Change Impacts in the United States.	Report
Jun	6/3/09	Introduction in Congress of H.R. 2685: National Climate Enterprise Act of 2009 to establish a national climate service interdepartmental Oversight Board chaired by OSTP.	Proposed Legislation
May	5/8/09	Introduction in Congress of H.R. 2407: National Climate Service Act of 2009 to establish a National Climate Service at National Oceanic and Atmospheric Administration to (1) advance understanding of climate variability, (2) provide forecasts, warnings, and other information to the public, and (3) support development of adaptation and response plans by Federal agencies, State, local, and tribal governments, the private sector, and the public.	Proposed Legislation
May	5/5/09	House Committee on Science and Technology, Subcommittee on Energy and Environment hearing on "Expanding Climate Services at the National Oceanic and Atmospheric Administration (NOAA): Developing the National Climate Service." Testimony from Dr. Jane Lubchenco, Dr. Arthur DeGaetano, Dr. Eric J. Barron, Dr. Philip Mote, Mr. Richard J. Hirn, Dr. Michael L. Strobel, Mr. David Behar, Mr. Paul Fleming, and Dr. Nolan Doesken.	Hearing
May	5/2/09	Columbia University Masters in Climate and Society program conference, The 350 Climate Conference, in New York to critically examine the question of "What is the safe upper limit of atmospheric carbon dioxide?" as well as explore the top strategies for reducing atmospheric carbon dioxide.	Conference
Apr	4/23/09	House Committee on Science and Technology, Subcommittee on Energy and Environment hearing on "Continued Oversight of NOAA's Geostationary Weather Satellite System." Testimony from Ms. Mary Ellen Kicza, Mr. David Powner, and Mr. George Morrow.	Hearing
Apr	4/22/09	House Committee on Science and Technology hearing on "Monitoring, Measurement and Verification of Greenhouse Gas Emissions II: The Role of Federal and Academic Research and Monitoring Programs." Testimony from Dr. Alexander "Sandy" MacDonald, Ms. Dina Kruger, Dr. Beverly Law, Dr. Patrick D. Gallagher, Dr. Michael Freilich, Dr. Richard Birdsey, Dr. Albert Heber.	Hearing

	4/21/09 – 4/24/09	Energy and Commerce Committee hearings on Markey-Waxman Clean Energy Jobs Legislation, Earth Week 2009. Focusing on energy issues.	Hearings
	4/17/09	EPA announces their findings in response to the landmark 2007 Supreme Court case Massachusetts v. EPA: Proposed Endangerment and Cause or Contribute Findings for Greenhouse Gases under the Clean Air Act.	Court Ruling (response)
	4/6/09	The World Meteorological Organization, U.S. National Academy of Sciences and the National Science Foundation host a Symposium on the International Polar Year that highlights the early accomplishments.	Symposium
Mar	3/31/09	Introduction of the American Clean Energy and Security Act of 2009 (ACES) to the House of Representatives. Passed by the House on 26 June.	Proposed Legislation
	3/31/09	House Subcommittee on Technology and Innovation hearing on "The Role of Research in Addressing Climate in the Transportation Infrastructure." Testimony from Mr. Steven Winkelman, Mr. Mike Acott, Mr. David Matsuda, Ms. Catherine Ciarlo, and Dr. Laurence R. Rilett.	Hearing
	3/30-09 – 3/31/09	In response to a request from Congress, the National Academies have initiated a suite of studies called Summit on America's Climate Choices, Earth's climate is changing. How will we respond? This summit will begin a process of open dialog among key stakeholders and decision makers, outline the key questions that need to be answered to move ahead, help inform and frame the context of the America's Climate Choices studies, and set the stage for national action on climate change.	Summit
	3/25/09	The Committee on Energy and Commerce, Subcommittee on Energy and Environment held a hearing titled, "Preparing for Climate Change: Adaptation Polities and Programs." Testimony from Thomas K. Karl, L.H.D., John Stephenson, Larry Schweiger, David Waskow, and Lord Christopher Monckton.	Hearing
	3/21/09	Joint hearing, House Committee on Science and Technology, Subcommittee on Energy and Environment on Perspectives on Climate Change. Testimony from Former Vice President Al Gore and Dr. Lomborg.	Hearing
	3/19/09	House Committee on Appropriations, Subcommittee on Commerce, Justice, Science, and Related Agencies hearing on "Climate Satellite Requirements, NASA and NOAA Programs." Testimony from Dr. Berrien Moore and Dr. Richard Anthes.	Hearing
	3/18/09	House Committee on Appropriations, Subcommittee on Commerce, Justice, Science, and Related Agencies hearing on "Critical Satellite Climate Change Datasets." Testimony from Dr. Antonio Busalacch, Dr. Tom Karl, Dr. Compton J. Tucker, and Dr. Robert Bindschadler.	Hearing
	3/17/09	House Committee on Appropriations, Subcommittee on Commerce, Justice, Science, and Related Agencies hearing on the "Status of Climate Change Science." Testimony from Dr. Susan Solomon,	Hearing
	3/12/09	Key messages from the Climate Congress, Global Risks Challenges and Decisions, held in Copenhagen, March 10-12, summarizing climate changes since the IPCC AR4.	Summary
	3/12/09	House Committee on Appropriations, Subcommittee on Commerce, Justice, Science, and Related Agencies hearing on "Climate Science – Empowering Our Response to Climate Change." Testimony from Katharine Jacobs and Dr. Timothy Killeen.	Hearing
		NRC reports Informing Decisions in a Changing Climate, Restructuring Federal Climate Research to Meet the Challenges of Climate Change released.	Report
		Draft EPA report, Technical Support Document, Endangerment Analysis for Greenhouse Gases under the Clean Air Act, responding to 2007 Massachusetts v. EPA ruling.	Report
		GAO report Climate Change, High Quality Greenhouse Gas Emissions Data are a Cornerstone of Programs to Address Climate Change released.	GAO

Feb	2/25/09	Committee on Ways and Means hearing on Hearing on "Scientific Objectives for Climate Change Legislation." Testimony from Dr. James Hansen, Dr. Brenda Ekwurzel, and Dr. John Christy, Submissions for the record from Laurie Williams and Allen Zabel, Richard Pauli, and Wayne Pacelle.	Hearing
	2/25/09	U.S. Senate Committee on Environment & Public Works Committee hearing on Update on the "Latest Global Warming Science." Testimony from R.K. Pachauri PhD, Christopher Field PhD, Howard Frumkin MD, MPH, DrPH, and William Happer PhD.	Hearing
	2/24/09	House Committee on Science and Technology, Subcommittee on Energy and the Environment Hearing "How Do We Know What We Are Emitting? Monitoring, Reporting and Verifying Greenhouse Gas Emissions." Testimony from Mr. John Stephenson, Ms. Jill Gravender, Ms. Leslie Wong, and Mr. Rob Ellis.	Hearing
Jan	1/9/09	Introduction in Congress of H.R. 367, Integrated Coastal and Ocean Observing System Act of 2009, to establish a National Integrated Coastal and Ocean Observation System that, among other uses, will improve the ability to measure, track, explain, and predict weather and climate change and natural climate variability.	Proposed Legislation
	1/8/09	Introduction in Congress of H.R. 300, National Oceanic and Atmospheric Administration Act, that maintains within NOAA programs to support efforts, on a continuing basis, to collect data and provide information and products regarding satellites, observations, and coastal, ocean, and Great Lakes information; and programs to conduct and support research and education and the development of technologies relating to weather, climate, and the coasts, oceans, and Great Lakes.	Proposed Legislation
	1/7/09	Introduction in Congress of S.22, Omnibus Public Land Management Act of 2009, that includes authorization for NOAA to conduct undersea research, ocean and coastal mapping integration, the integrated coastal and ocean observation system, federal ocean acidification research and monitoring, and coastal and estuarine land conservation. (Passed in the Senate 1/15/09, failed passage in the House 3/11/09.)	Proposed Legislation
		NRC's second assessment of the USCCSP, Restructuring Federal Climate Research to Meet the Challenges of Climate Change (prepublication version) released.	Report
		NRC report Disaster Risk Management in an Age of Climate Change: A Summary of the April 3, 2008 Workshop of the Disasters Roundtable released.	Report
		CCSP reports, Thresholds of Change in Ecosystems, Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region, Atmospheric Aerosol Properties and Climate Impacts, Best Practice Approaches for Characterizing, Communicating, and Incorporating Scientific Uncertainty in Decision Making, and Past Climate Variability and Change in the Arctic and at High Latitudes released.	Report

	2008	Activity / Event	Type
		NRC reports Ensuring the Climate Record from the NPOESS and GOES-R Spacecraft: Elements of a Strategy to Recover Measurement Capabilities Lost in Program Restructuring, Ecological Impacts of Climate Change, Ensuring the Climate Record from the NPOESS and GOES-R Spacecraft: Elements of a Strategy to Recover Measurement Capabilities Lost in Program Restructuring, Options to Ensure the Climate Record from the NPOESS and GOES-R Spacecraft: A Workshop Report, and Understanding and Responding to Climate Change released.	Reports
Dec		CCSP reports, Abrupt Climate Change and Re-analyses of Historical Climate Data for Key Atmospheric Features, Implications for Attribution of Causes of Observed Changes, released.	Report
Nov		CCSP report Trends in Emissions of Ozone-depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure, released.	Report
Sep		CCSP report Uses and Limitations of Observations, Data, Forecasts, and Other Projections in Decision Support for Selected Sectors and Regions released.	Report
Jul	6/22/08	Senate Committee on Environment and Public Works hearing entitled, "An Update on the Science of Global Warming and its Implications." Testimony from Jason Burnett, Dr. Kevin E. Trenberth, and Dr. Roy Spencer.	Hearing

Jun	6/10/08	House Select Committee on Energy Independence and Global Warming hearing on "Global Warming Effects on Extreme Weather California Wildfires, Midwest Floods, Other Events Prompt Question: What is Warming's Link to Wild Weather?" Testimony from Dr. Jimmy O. Adegoke. Heather Cooley, Dr. Jay S. Golden, Angela Licata, and Dan Keppen.	Hearing
		CCSP report Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems, released.	Report
	6/24/08	Senate Committee on Commerce, Science, and Transportation hearing **o**n Climate Change Impacts on the Transportation Sector. Testimony from The Honorable Thomas J. Barrett, Dr. James M. Turner, Dr. Thomas C. Peterson, The Honorable John D. Porcari, Dr. G. Edward Dickey, Mr. David Friedman, Mr. Edward Hamberger, Mr. John M. Meenan, and Mr. Mead Treadwell.	Hearing
	6/19/08	House Subcommittee on Energy and Environment hearing "An Insecure Forecast for Continuity of Climate and Weather Data: The NPOESS Weather Satellite Program." Testimony from Mr. David Powner and Vice Admiral Conrad C. Lautenbacher Jr.	Hearing
		CCSP report Weather and Climate Extremes in a Changing Climate. Regions of focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands released.	Report
Jun		CCSP reports, Preliminary Review of Adaptation Options for Climate-sensitive Ecosystems and Resources and Climate Models: An Assessment of Strengths and Limitations for User Applications, released.	Report
		Senate, Committee on Energy and Natural Resources hearing on Climate Change in Coastal Regions. Testimony from Thomas J. Wilbanks, Virginia Burkett, Terry Wallace, Ted Falgout, Charles, T. Drevna, and Lisa P. Edgar.	Hearing
May	5/8/08 – 5/10/08	Influence of Climate Change on the Changing Arctic and Subarctic Conditions. The NATO - Russia Advanced Research Workshop held in Liège, Belgium.	Workshop
	5/6/08 – 5/9/08	World Climate Research Programme, World Modelling Summit for Climate Prediction, held in Reading, U.K.	Summit
		CCSP report, The Effects of Climate Change on Agriculture, Biodiversity, Land, and Water Resources, released.	Report
		The Revised Research Plan for the U.S. Climate Change Science Program released.	Report
Apr	4/29/08	Select Committee on Energy Independence and Global Warming hearing on "Rising Tides, Rising Temperatures: Global Warming Effects on Oceans." Testimony from Sylvia Earle, Dr. Vikki Spruill, Dr. Jane Lubchenco, and Dr. Joan Kleypas.	
	4/14/08 – 4/18/08	Department of Energy workshop, Exploring Science Needs for the Next Generation of Climate Change and Elevated-CO2 Experiments in Terrestrial Ecosystems, held Arlington, Virginia.	Workshop
	4/9/08	Select Committee on Energy Independence and Global Warming hearing "Healthy Planet, Health People: Global Warming and Public Health." Testimony from Howard Frumkin, M.D., M.P.H., Ph.D., Jonathan Patz, M.D., M.P.H., Georges Benjamin, M.D., F.A.C.P., F.A.C.E.P., Mark Jacobson, Ph.D., and Dana Best, M.D., M.P.H., F.A.A.P.	Hearing
Mar	3/28/08	Joint press release from *the National Snow and Ice Data Center (NSIDC), the British Antarctic Survey (BAS), and the Earth Dynamic System Research Center about the* Wilkins ice shelf has begun to collapse because of rapid climate change in a fast-warming region of Antarctica.	Press release
	3/27/08	Fact Sheet, Department of State, Bureau of Oceans and International Environmental and Scientific Affairs on United States Global Engagement on Climate Change and Public Health.	Statement
		CCSP report, Impacts of Climate Variability and Change on Transportation Systems and Infrastructure -- Gulf Coast Study, released.	Report

		NRC, *Potential Impacts of Climate Change on U.S. Transportation*. (U.S. Army Corp of Engineers among groups funding of this work.)	Report
		NRC Potential Impacts of Climate Change on U.S. Transportation: Special Report 290.	Report
		NRC, Division of Behavioral and Social Sciences and Education workshop on New Directions in Climate Change Vulnerability, Impacts and Adaptation Assessment. Supported by EPA, USGS, NASA, and DoE.	Workshop
Feb	2/14/08	Select Committee on Energy Independence and Global Warming hearing "Fire and Rain: How Destruction of Tropical Forests is Fueling Climate Change." Testimony from Dr. Thomas Lovejoy, Mr. Stuart Eizenstat, and Ms. Stephanie Meeks.	Hearing
Jan	1/17/08	Select Committee on Energy Independence and Global Warming hearing "On Thin Ice: The Future of the Polar Bear." Testimony from Mr. Dale Hall, Mr. Randall Luthi, Dr. Steven Amstrup, Ms. Jamie Rappaport Clark, Ms. Deborah Williams, and Ms. Kassie Siegel.	Hearing
	1/16/08-1/18/08	Climate Change: Science and Solutions, 8th National Conference on Science, Policy, and the Environment; National Council for Science and Environment, DC.	Conference

	2007	**Activity / Event**	**Type**
		NRC reports Evaluating Progress of the U.S. Climate Change Science Program: Methods and Preliminary Results, Analysis of Global Change Assessments: Lessons Learned (2007), Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (2007), Environmental Data Management at NOAA: Archiving, Stewardship, and Access, and Understanding Multiple Environmental Stresses: Report of a Workshop (2007) released.	Reports
Nov	11/14/07	Senate Committee on Commerce, Science, and Transportation Subcommittee on Science, Technology, and Innovation Hearing "A Time for Change: Improving the Federal Climate Change Research and Information Program." Testimony from Dr. John Marburger III, Dr. Jack A. Kaye, Dr. Donald F. Boesch, Dr. Braxton Davis, Dr. Peter C. Frumhoff, Dr. Lynne M. Carter, Dr. John R. Christy, and Dr. Richard Moss.	Hearing
		CCSP reports, North American Carbon Budget and Implications for the Global Carbon Cycle and Decision support experiments and evaluations using seasonal to interannual forecasts and observational data released.	Report
Oct	10/22/07 – 10/23/07	Climate Information: Responding to User Needs, a national workshop sponsored by the University of Maryland, NOAA, NASA, and the American Meteorological Society to foster dialogue between the providers of climate change information and its diverse user community.	Workshop
	10/18/07	Introduction in Congress of S. 2204, Global Warming Wildlife Survival Act, in addition to similar requirements to H.R. 2338, requires the Secretary of Commerce to protect, maintain, and restore coastal and marine ecosystem to better withstand stresses of climate change, and to establish a coastal climate change resiliency planning and response program; and USGS to examine ecological impact of climate change on imperiled species in each U.S. ecosystem. (Not voted on.)	Proposed Legislation
	11/14/07	Introduction in Congress of S. 1581/H.R. 4174, Federal Ocean Acidification Research And Monitoring Act of 2008, requires NOAA, NASA, and NSF to carry out research and monitoring of ocean acidification. (Passed in House, not voted on in Senate.) (Not voted on.)	Proposed Legislation
	11/05/07	Introduction in Congress of S. 2307, Global Change Research Improvement Act of 2006, that includes several amendments to the Global Change Act of 1990; renames the National Climate Program Act as the National Climate Service Act of 2007 and requires NOAA to establish a National Climate Service that includes a national center and a network of regional and local facilities for operational climate monitoring and	Proposed Legislation

		prediction; and requires NOAA to establish a program of scientific research on abrupt climate change. (Not voted on.)	
		Release of the final of the four reports of the IPCC's Fourth Assessment (AR4) Climate Change 2007.	IPCC
Sep	09/14/07	Northwest Passage open for the first time since satellite measurements began.	Article
		GAO report Climate Change, Agencies Have Data-Sharing Policies but Could Do More to Enhance the Availability of Data from Federally Funded Research released.	GAO
		Publication of IPCC Fourth Assessment on Climate Change (AR4).	IPCC
		Release of the report on the National Research Council's first assessment of the USCCSP, Evaluating Progress of the U.S. Climate Change Science Program: Methods and Preliminary Results.	Report
Aug	8/07/07	Federal district court ruling that the Administration violated the Global Change Research Act by failing to produce a national global change research plan that was due by July 2006 and a scientific assessment of global change impacts that was due in November 2004. Both to be produced no later than the end of May 2008.	Court Ruling
		GAO report *Climate Change*: Agencies Should Develop Guidance for Addressing the Effects on Federal Land and Water Resources released.	GAO
		Release of CCSP Aerosol Properties and their Impacts on Climate report.	Report
Jul		Release of three CCSP reports, Scenarios for Greenhouse Gas and Review of Integrated Scenario Development and Application, and Effects of Climate Change on Energy Production an Use in the United States.	Report
May	5/16/07	House Science and Technology Committee hearing on "The State of Climate Change Science 2007: Working Group III: Mitigation of Climate Change." Testimony from Dr. Mark Levine, Dr. William A. Pizer, Mr. Stern Plotkin, and Dr. Roger Pielke, Jr.	Hearing
	5/16/07	Introduction in Congress of H.R. 2342, National Integrated Coastal and Ocean Observation Act of 2008, making NOAA the lead agency for a National Integrated Coastal and Ocean System that, among other uses, will improve the ability to measure, track, explain, and predict weather and climate change and natural climate variability; and fulfill the nation's international obligations to contribute to the global earth and ocean observation systems. (Passed by House, not voted on by Senate.)	Proposed Legislation
	5/16/07	Introduction in Congress of H.R. 2338, Global Warming Wildlife Survival Act, that includes a requirement for the Secretary of the Interior to establish the National Global Warming and Wildlife Science Center within the USGS to: (1) conduct scientific research on national issues related to the impacts of global warming on wildlife and its habitat and mechanisms for adaptation or mitigation of such impacts; and (2) provide scientific support to federal land management agencies and federal wildlife agencies regarding such issues. (Not voted on.)	Proposed Legislation
	4/2/07	Supreme Court ruling in Massachusetts v. EPA, finding that EPA has the authority to regulate CO_2 and other greenhouse gases under the Clean Air Ac and remanded the section 202 endangerment finding to EPA for revision in light of their decision.	Court Ruling
Feb	02/08/07	U.S. House of Representatives, Committee on Science and Technology hearing on The State of Climate Change Science 2007.	Hearing
	2/07/07	Introduction in Congress of H.R. 906, Global Change Research and Data Management Act of 2007, intended to promote and coordinate climate change research. (Not voted on.)	Proposed Legislation

Pre-2007	Activity / Event	Type
2006	NRC reports Completing the Forecast: Characterizing and Communicating Uncertainty for Better Decisions Using Weather and Climate Forecasts and Surface Temperature Reconstructions for the Last 2,000 Years released.	Reports
	CCSP reports, Temperature Trends in the Lower Atmosphere—Steps for Understanding and Reconciling Differences, released. (May)	Report
2005	NRC reports Thinking Strategically: The Appropriate Use of Metrics for the Climate Change Science Program, Decision Making for the Environment: Social and Behavioral Science Research Priorities, and Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties (2005) released.	Reports
	GAO reported, Climate Change Assessment: Administration Did Not Meet Reporting Deadline. Responding to GAO's recommendation, CCSP requested an extension from Congress for completing the required products. (April 14)	GAO
2003	NRC reports Understanding Climate Change Feedbacks and Estimating Climate Sensitivity: Report of a Workshop released.	Reports
	Hearing before U.S. Senate Committee on Commerce, Science and Transportation Committee on Abrupt Climate Change. Testimony from R. Alley and T.E. Graedel (accompanied by A. Janetos, D. Liverman and A. Solow).	Testimony
	GAO report *Climate Change*: Preliminary Observations on the Administration's February 2002 *Climate* Initiative released. (October)	GAO
	GAO report *Climate Change*: Information on Three Air Pollutants' *Climate* Effects and Emissions Trends released. (March)	GAO
	Publication of the Strategic Plan for the U.S. Climate Change Science Program, stating that a scientific assessment would be produced in the form of 21 short reports between 2005 and 2007. (July)	Report
2002	NRC report Abrupt Climate Change: Inevitable Surprises released.	Report
	A new administration in 2001 combined USGCRP and CCRI in the Climate Change Science Program (CCSP). The vision for CCSP is "a nation and the global community empowered with the science based knowledge to manage the risks and opportunities of change in the climate and related environmental systems." (February)	Research Program
2001	NRC report A Climate Services Vision: First Steps Toward the Future released.	Report
	Release of the first U.S. National Assessment of the Potential Consequences of Climate Variability and Change as required under the Global Change Research Act. (November)	1st National Assessment
	Release of IPCC's Third Assessment Report, Climate Change 2001.	IPCC
	President Bush launched the Climate Change Research Initiative (CCRI) "to study areas of uncertainty [about global climate change science] and identify priority areas where investments can make a difference."	Research Program
1995	Release of the IPCC's Second Assessment Report, Climate Change 1995.	IPCC
1990	Second Climate Conference held on 29 Oct – 7 Nov, Geneva. Eventually, however, developments at the conference led to the establishment of the United Nations Framework Convention on Climate Change (UNFCC).	Conference

	Enactment of U.S. Global Change Research Act, United States Code, Title 15, Chapter 56A - Global Change Research, requires the establishment of a United States Global Change Research Program aimed at understanding and responding to global change, including the cumulative effects of human activities and natural processes on the environment, to promote discussions toward international protocols in global change research, and for other purposes.	Legislation
	Release of the IPCC's First Assessment Report.	IPCC
1988	The Intergovernmental Panel on Climate Change (IPCC) established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). Its main objective is to assess scientific, technical, and socio-economic information relevant to the understanding of human induced climate change, the potential impacts of climate change, and options for mitigation and adaptation.	Report
	1st federally coordinated program supporting climate change research, The U.S. Global Change Research Program (USGCRP), began as a presidential initiative in 1988. (It received congressional support in 1990 under the Global Change Research Act.)	Research program
1979	First World Climate Conference is held in Geneva, 12-23 February, sponsored by the WMO. It led to the establishment of the World Climate Programme and the World Climate Research Programme. It also led to the creation of the IPCC by 1988.	Conference
1978	National Climate Program Act enacted by Public Law 95–367 (Sept. 17, 1978) with the purpose "to establish a national climate program that will assist the Nation and the world to understand and respond to natural and man-induced climate processes and their implications." (Amended Through P.L. 106–580, Dec. 29, 2000.)	Legislation

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE (DD-MM-YY) July 2009	2. REPORT TYPE Study	3. DATES COVERED (From – To)
4. TITLE AND SUBTITLE Climate Change: Issues in the Science and Its Use		5a. CONTRACT NUMBER DASW01-04-C-0003
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBERS
6. AUTHOR(S) Christine Youngblut		5d. PROJECT NUMBER
		5e. TASK NUMBER IDA Central Research Program C2222
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSES Institute for Defense Analyses 4850 Mark Center Drive Alexandria, VA 22311-1882		8. PERFORMING ORGANIZATION REPORT NUMBER IDA Document D-3904
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Institute for Defense Analyses 4850 Mark Center Drive Alexandria, VA 22311-1882		10. SPONSOR'S / MONITOR'S ACRONYM IDA
		11. SPONSOR'S / MONITOR'S REPORT NUMBER(S) IDA Document D-3904

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; unlimited distribution: 29 January 2010.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The U.S. is on the threshold of major changes in how it conducts climate change science research. These changes are being driven by several imperatives. One driving force is the growing recognition of the role that societal and ecological processes play in climate change. Another is the need to better support stakeholders who require climate-related information for the development of mitigation policy and adaptation activities. Wide expectations that the new administration will give new impetus to U.S. climate change research, along with increased Congressional interest also play a role. Finally, a new consensus that climate change is progressing much more rapidly than projected just two years ago adds a sense of urgency to these topics.
This paper presents a high level picture of this state of events and the key issues that have arisen. It is one in a series of papers looking at climate change issues. The purpose of this series of papers is to raise awareness of the full scope of climate-related concerns. By identifying the key issues, each paper identifies potential opportunities for strengthening the U.S. response to climate change.

15. SUBJECT TERMS
Climate Change; Science; Decision Support.

16. SECURITY CLASSIFICATION OF: Unclassified			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Dr. Christine Youngblut
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified	Unlimited	50	19b. TELEPHONE NUMBER (Include Area Code) (703) 845-6636

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std, Z39.18